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THE EFFECTS OF BIODYNAMIC STRESS ON WORKLOAD IN HUMAN OPERATORS

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The objective of this research was to assess the effect of high intensity noise stress and of sustained acceleration on human operator workload and performance. Workload was measured via three different methodologies. Subjective workload was measured with the Subjective Workload Assessment Technique (SWAT); performance-based measures were derived from single and dual psychomotor task performance; and physiological parameters included heart rate, blood pressure, total eye blinks and blink duration, forearm electromyogram and evoked response EEG, especially the latency and amplitude of the P300 peak.

The dual task workload consisted of a primary tracking task and a secondary task of monitoring a modified Radar Homing and Warning display. Two levels of pink noise (90 and 100 dB A-weighted) and two levels of sustained acceleration (2.75 and 3.75 G_z) served as the biodynamic stressors. Nine subjects performed the dual task in the Armstrong Aerospace Medical Research Laboratory human centrifuge. Exposures were 60 seconds long during which time subjects' noninvasive physiological parameters were monitored in either noise or acceleration

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conditions. Subjects gave a subjective workload rating (SWAT) after each exposure.

Noise stress significantly increased subjective mental workload (SWAT scores) as well as mean arterial blood pressures and reduced subjects' reaction times to targets, but had no significant effect on primary tracking error scores, percent hits on the secondary task, or any of the other physiological measures. Acceleration stress significantly increased SWAT scores, primary tracking error scores, heart rate and total eye blinks as well as the standard deviation of the forearm EMG.

The standard deviation of the EMG measured from the tracking forearm muscle of the subjects correlated significantly with most of the workload variables. P300 latencies and amplitudes increased with increasing task difficulty but were unaffected by acceleration or noise. SWAT correlated significantly with both performance-based and physiologically-based workload variables but the latter two methodologies did not correlate well or significantly with each other. The results indicate that biodynamic stressors such as noise and acceleration adversely affect subjective operator workload without affecting objective task performance and that physiological workload measures such as eye blink and blink duration are ineffective in the acceleration environment.

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PREFACE AND ACKNOWLEDGMENTS

This research was conducted in the Acceleration Effects Branch of the Biodynamics and Bioengineering Division of the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL). The AAMRL is a part of the Human Systems Division of the Air Force Systems Command, United States Air Force. The Acceleration Effects Branch is located in Building 33 of Area B, Wright-Patterson AFB, Ohio 45433-6573.

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I. INTRODUCTION

The modern aircraft cockpit is less than the ideal work station for the human. In modern fighter aircraft cockpits, pilots are routinely subjected to 120 dB A-weighted sound level (100 dB at the ear) and must be able to perform complex cognitive tasks while exposed to acceleration levels up to $+9G_z$. In addition, new developments in digital cockpit displays and integrated weapons system avionics have significantly altered the role of the pilot from that of a skilled, manual control operator to that of an executive manager of an integrated weapons system (Schiflett, 1980). Selecting and displaying information on various multi-purpose displays, processing information on the heads-up and heads-down displays and coordinating weapons systems while maneuvering a high performance aircraft can impose a serious cognitive load on the pilot. Humans, operating other complex man-machine systems under a variety of both normal and abnormal conditions, also face situations imposing serious cognitive loads. The human operator has a limited capacity to process and respond to information (Broadbent & Gregory, 1965; Eggemeier & O'Donnell, 1986; Navon & Gopher, 1979; Norman & Bobrow, 1975; Shingledecker, 1983; Wickens, 1984). System designers must have a metric for measuring that portion of the operator's limited capacity which is actually required to perform a particular set of tasks. As a result, mental capacity or workload methodologies have been developed (Donchin, 1979; Jex, 1976; Mulder, 1979, Pew, 1979; Sheridan,

1980; Williges & Wierwille, 1979). Mental workload, or workload, refers to the demands imposed by the system on the operator's capacity for processing information and acting on it (Gopher & Donchin, 1986; O'Donnell & Eggemeier, 1986).

Unfortunately, few measurement techniques exist which are able to provide an objective, reliable and valid estimate of the subtle differences in workload introduced by new cockpit systems. Compounding this problem is the fact that the majority of these integrated cockpit systems have been developed and evaluated on the ground by airframe manufacturers in non-stress environments. Little is known about the effect of noise stress or acceleration stress on the human operator using these systems, and how these stressors affect workload and the operator's performance. Noise stress was selected for this research because noise levels can be as high as 120 dB A-weighted sound level in the F-16 cockpit (Hille, 1979). Acceleration stress was selected because pilots can be subjected to short-duration high G exposures during air-to-air combat or air-to-surface weapons delivery and they must be able to perform under sustained acceleration (Gillingham, Plentzas & Lewis, 1985).

What is needed is a method for predicting and quantifying, subjectively and objectively, the effects of stressors such as noise and acceleration in the advanced fighter aircraft cockpit on pilot performance and mental workload capacity.

The objective of this research was to evaluate the effect of these biodynamic stressors, noise and acceleration, on human operator mental workload and to contribute to the methodology of monitoring, measuring and perhaps predicting mental workload in the aircraft cockpit.

II. BACKGROUND

Mental workload is a construct which has been studied extensively, reported throughout the literature and used in everyday language by researchers measuring human performance; yet, one, universal definition of mental workload still does not exist. Almost everyone can imagine examples where two or more individuals comparably perform the same type of task, whether it is performed in a factory, in an aircraft, on an athletic field or in the classroom. Yet, it is clear that although these individuals have achieved the same objectively measured performance level, some of these individuals must expend much more energy than the others in order to achieve the same level of performance. It is this effort or "cost" to the individual that is termed workload and which has eluded those who try to measure it.

Performance measures alone cannot account for this cost to the individual and cannot of themselves explain workload. Humans can increase their efforts as a task becomes more difficult, thus increasing perceived workload, while simultaneously maintaining high performance standards. Because individuals can achieve the same performance levels with varying levels of effort, workload has been found to correlate only moderately with performance measures; additional techniques and measures must be used to adequately describe the workload. Furthermore, some techniques and measures are more diagnostic than others, especially if

a task is performed in an abnormal environment.

Numerous studies have been conducted over the last decade to assess the functional relationship between workload and a number of subjective, behavioral and physiological measures. Researchers have developed a number of measures of physical workload which effectively relate the amount of work accomplished to the energy cost (Singleton, Fox & Whitfield, 1973). Such direct measures have eluded mental workload researchers. With the advent of computers and the technology revolution, man's physical workload has been redirected toward more mental activities; modern man must be able to perform attention and information processing activities in many factory jobs since robots now perform many of the menial, labor-intensive tasks. This transition from the physical to cognitive workload role of man has been a popular topic with cognitive psychologists. Two recent publications have summarized the current thinking about how to both measure mental workload (O'Donnell & Eggemeier, 1986) and adequately describe its multi-dimensional characteristics (Gopher & Donchin, 1986).

A number of models have been developed to explain how man can do two things at once, but the essence of the major theories is that the human information processing system is finite. Man has a finite capacity or capacities for processing and acting upon information; different task situations require different levels of capacity expenditure (Gopher & Donchin, 1986). In terms of mental workload, an individual in a high workload situation has little or no "spare capacity" to cope with an additional task or responsibility. Alternatively, the individual in a low workload situation has a virtually untapped capacity.

What the precise nature and location of this capacity or capacities is has been a topic of considerable debate (Kantowitz, 1985; Navon & Gopher, 1979; Norman & Bobrow, 1975).

Many of the current workload measures are promising but, generally, they have been validated primarily in laboratory environments under quiet, one G conditions. Each of these measures, grouped into subjective, behavioral or performance-based and physiologically-based methodologies, has its strengths and weaknesses. Because of the complexity of the workload construct, it is doubtful whether any one of these three methodologies can completely and adequately describe mental workload associated with any task in any situation or environment. The combination of all three approaches might be required to characterize the total workload. All three of these methodologies will be reviewed.

Subjective Measurement of Workload

A subjective measure of mental workload is one that is based on a subject's direct estimate or comparison judgment of the workload experienced at a given moment (Reid & Nygren, 1988). Subjective measures require operators to judge and to report their own experience of the workload imposed by performing a particular task. Rating scales are a frequently used version of this technique and subjective measures are the most frequently used method for workload assessment (Williges & Wierwille, 1979). Subjective workload measures are popular because of several reasons. First, subjective measures enjoy high face validity. If operators voice their opinion that the operation of a certain system requires too much work then design alternatives are usually found. Secondly, subjective measures can be more direct than many of the other

measures. Humans are excellent integrators. Whether it's judging a decrease in the temperature outside, beautiful women, or an ice skating routine in the Olympics, humans show a remarkable sense of placing things on an ordinal scale. Some researchers (Johanssen, Moray, Pew, Rasmussen, Sanders and Wickens, 1979) have even concluded that if an operator believes he or she is task loaded and under stress in a situation, then one must conclude that he or she actually is, regardless of what other measures or indices are indicating. Finally, the ease of using and obtaining subjective measures makes them very adaptable to operational environments. Very little, if any, instrumentation is required and the timing of data collection can be tailored to fit the particular operational environment. Some of the disadvantages of subjective techniques include factors that can influence the degree of load actually experienced by the operator (e.g. confounding of mental and environmental stressor) and methodological constraints that can influence the reported levels of load, such as delay in reporting workload ratings (O'Donnell & Eggemeier, 1986).

A Subjective Workload Assessment Technique, or SWAT technique has now been developed (Reid, Shingledecker, Nygren & Eggemeier, 1981). SWAT is a scaling procedure that has been developed for use in applied settings. What distinguishes SWAT from most other subjective rating methods is that it was rigorously developed to be rooted in formal measurement theory, specifically conjoint measurement theory (Reid & Nygren, 1988).

SWAT has three dimensions. The first dimension is Time Load, which means both the time available to perform a task or tasks as well as task

overlaps. The second dimension deals with task factors such as difficulty, complexity or effort; this dimension also encompasses the concept of mental capacity or capacities referred to previously and termed Mental Effort Load. Mental effort load involves such processes as performing calculations, making decisions, attending to information sources, placing information in short-term memory and retrieving it, retrieving relevant information from long-term memory and estimation. The third dimension encompasses a number of operator variables such as motivation, training, fatigue, health and emotional state. This dimension may be represented by such specific stressors as fear of physical harm, fear of failure, tension, unfamiliarity and disorientation, to name a few. In addition, physical stressors such as temperature, vibration, G-forces and noise may also be a source of irritation to the operator when they are present at low levels and performance blocks when present at high levels. This type of workload effect is called Psychological Stress Load and is defined as anything that contributes to the operator's confusion, frustration and/or anxiety. In SWAT, subjects are instructed to reflect the effect of the physical stress effect in this "catch-all" dimension as either low, medium or high. Conjoint measurement's power lies in the fact that it uses only observed ordinal or rank order information about the complex construct in order to empirically establish a combination rule that fits a respondent's data.

The combination of these three dimensions with a three point (low, medium, high) rating scale, results in a three dimensional-workload construct, resembling a 27 cell cube. Each of the cells of this cube is represented by a combination of one descriptor for each of the

dimensions, yielding a total of twenty-seven cells or combinations. These descriptors are typed on a set of index cards so that each cell is represented by a separate card. This deck of cards is the medium employed in obtaining the rater's judgment of the relative workload each combination represents to him or her. Subjects are required to perform a card sort procedure where they place the cards representing the 27 cells of the three-dimensional matrix in rank order beginning with the combination of descriptors that represents the lowest workload situation (1, 1, 1) and ending with the combination that represents the highest (3, 3, 3). The 25 cards between are rank ordered. This order is then used for scaling the input data for the conjoint measurement analysis. The output of the conjoint analysis is an overall scale ranging from 0-100 which represents the combination of all three dimensions. Subjects then respond to the task being evaluated with three numbers, one for each of the dimensions and ranging from 1 to 3; 1 is a low workload, 2 is medium and 3 is high. These ratings on each of the dimensions are subsequently used to identify the score on the overall scale of workload that had been derived from the card sort procedure. As noted above, these scores range from 0 to 100.

SWAT has been widely used in aircraft and control centers, both in simulation as well as operational settings (Reid & Nygren, 1988). SWAT has been demonstrated to be a post-hoc scaling procedure that allows meaningful assignment of numbers to individuals' subjective impressions of the mental workload associated with performing various tasks. It has been used to evaluate workload associated with both short duration (less than 60 seconds) as well as relatively long duration (up to 15 minutes)

tasks (Reid & Nygren, 1988). SWAT has not been used in the past to separate out the effect of physical stressors (such as acceleration, noise and vibration) on mental workload and its overall utility in the bioenvironment (heat, cold, vibration, acceleration, impact, noise and fatigue) has yet to be evaluated.

Behavioral or Performance-Based Workload Measures

Performance-based measures develop an index of workload from some aspect of operator performance. There are two major types of performance-based measures (O'Donnell & Eggemeier, 1986). Primary task measures can indicate the adequacy of operator performance on the principal task or system function of interest (e.g. the number of bombs on a target during a training run made by a pilot flying an aircraft). Secondary task measures are based on the operator's ability to perform an additional or secondary task (e.g. responding to a radio communications task) concurrently with the primary task of interest (e.g. dropping bombs).

In the single primary task measure approach, a single aspect of primary task performance (reaction time, number of errors, tracking error score) is used as the index of workload. The use of single primary task measures of workload has produced some instances in which levels of load induced by manipulation of task difficulty were discriminated, and others in which they were not (O'Donnell & Eggemeier, 1986).

A very frequently used workload assessment procedure is secondary task methodology which requires concurrent performance of two tasks by the operator. The primary task is the activity of central interest (dropping bombs) and an estimate of primary task workload is derived

from performance of an additional task (e.g. communications). The secondary task workload methodology is often used to measure the presumed spare or reserve processing capacity left over by a primary task. One derives this measure from levels of performance on the secondary task, which serves as a index of the spare capacity which is available while the operator performs the primary task (O'Donnell & Eggemeier, 1986). Two major categories of secondary task methodology (Knowles, 1963) can be distinguished by emphasizing either the primary or secondary task performance: (a) the loading task and (b) the subsidiary task paradigms. In the former category, the operator is instructed to maintain secondary task performance, even at the cost of primary task performance. This technique assumes the operator will shift his/her attention from the primary task to the secondary task causing breakdowns in primary task performance. The latter category, the subsidiary task paradigm, is the more frequent application of the secondary task technique and is a measure of capacity. Operators are instructed to avoid degraded primary task performance at the expense of the secondary task. The secondary task in this category is not used to load the primary task, but rather, is used to determine how much additional processing can be undertaken while the primary task is being performed at single task baseline levels (Knowles, 1963).

Performance measures, as do the other workload methodologies, give relative measures of workload. If the primary task is a reaction time task, for example, a mean reaction time can be calculated based upon the number of trials and subjects. If the addition of a secondary task results in a 20% longer mean reaction time for the primary task, this

increase can be considered a relative measure of increased mental workload. One should not say mental workload increased 20% because if one were to measure the workload with another performance measure (such as number of errors), there may not be a 20% increase (in errors). These increases have not been demonstrated to be linear functions and, most likely, they are not. Performance-based measures do provide the researcher with the ability to compare relative increases in workload and, if used carefully, can be quite diagnostic in certain situations (O'Donnell & Eggemeier, 1986).

Physiologically-Based Workload Measures

Physiological measures infer the level of workload from some aspect of the operator's physiological response to a task or system demand (O'Donnell & Eggemeier, 1986). These measures may include central nervous system responses (e.g. the event related potential measured from the scalp), autonomic responses (e.g. pupillary reflex) or peripheral measures (e.g. eye movements and muscle activity). The principal physiological variables recorded for workload analysis include measures of brain function (electroencephalogram or EEG), eye function (electro-oculogram or EOG), cardiac function (electrocardiogram or ECG or EKG) and muscle function (electromyogram or EMG).

The EEG recorded from surface electrodes placed directly on the scalp is a practical procedure for directly tapping the brain's activity during the performance of a task (O'Donnell and Eggemeier, 1986). Some attempts to quantify the amount of EEG power in specific bands (e.g. alpha, beta, theta and delta) of the EEG spectrum have been attempted; these have been generally disappointing as indications of workload,

except where overall activation clearly changes as a function of the load imposed. The development of the cortical evoked response, on the other hand, has shown some promise in assessing specific workload variables. In the transient cortical evoked response technique, stimuli are presented at a relatively slow rate, such as one second or longer between stimuli. This approach allows the effects of the stimulus on brain activity to dissipate prior to a second stimulus and the transient response of the brain is, therefore, isolated in the evoked response. The first 250 milliseconds of the response have been related to sensory characteristics of the stimulus, such as image sharpness, color and intensity (O'Donnell, 1979; Regan, 1972) and to some early cognitive events.

For workload research purposes, it is the third major positive peak of the evoked response that is of interest (Figure C6). This peak, called the P300 or P3, frequently occurs in the time period between 250 and 600 milliseconds, depending on the task. Numerous studies have confirmed that the P300 is elicited only when the subject is actively processing information, and that it is elicited only by stimuli which have some relevance to the task being performed by the subject (Beck, 1975). The amplitude and latency of the P300 wave appears to be sensitive to different aspects of the stimulus situation; amplitude has been shown to vary monotonically with stimulus probability and is directly proportional to the degree of subjective surprise at the appearance of a stimulus (O'Donnell & Eggemeier, 1986). The latency of the P300 wave has been suggested as indicating the amount of time the subject takes in evaluating a stimulus (Donchin, 1981). The latency and

amplitude of the P300 may be used to assess differences in task-induced difficulty of processing and responding to information.

One relatively standardized paradigm has evolved for evaluating the P300 which has been used in applied situations. The "oddball" paradigm (Gopher & Donchin, 1986) allows assessment of certain types of workload analysis of the P300 amplitude generated to a relatively nonintrusive secondary task. The typical procedure involves the presentation of an audio task through a headset to a subject who is tracking or performing some task. The audio task usually involves two tones, one high and one low, with one tone occuring more frequently than the other. The subject is instructed to attend to the rarer tone and to count the number of times the tone occurs during a visual-motor task. The P300 amplitude to the rarer tone is then obtained and analyzed; this amplitude has been shown to vary as a function of a number of conditions, such as task difficulty, task relevance and occurrence of the rare tone (Donchin, 1981).

Physiological measures other than the P300 include eye blink and blink duration, heart rate and blood pressure. Measures of closure duration and blink pattern have been successful indicators of time-on-task effects that might indirectly index levels of workload (Oster and Stern, 1980). One of the problems plaguing eye blink duration and blink frequency analysis is that it is difficult to determine whether the observed effects were truly due to workload differences or simply resulted from changes in motivation or fatigue (O'Donnell & Eggemeier, 1986). The EKG, blood pressure and other factors relating to cardiac function have all been used as physiological indices of stress

or workload. Heart rate has been the most widely used indicator of workload, since it is relatively easy to obtain and had been shown to be a sensitive workload measure (Blitz, Hoogstraten & Mulder, 1970; Boyce, 1974; Hasbrook & Rasmussen, 1970; Kalsbeek, 1963, 1968, 1973; Krzanowski & Nicholson, 1972; Spyker, Stackhouse, Khalafalla & McLane, 1971; Stackhouse, 1973, 1976). Heart rate and heart rate variability are promising but are considered by some to be unvalidated measures of workload (O'Donnell & Eggemeier, 1986). Other physiological measures, such as the muscle EMG, are not directly related to cognition but have shown promise as indicators of mental workload.

The EMG has been used to obtain a measure of "mental work," or tension in a muscle not directly related to the visual-motor task being performed by the subject. For assessing mental workload, the relatively static tension level of a muscle not directly involved in task performance is usually monitored (O'Donnell & Eggemeier, 1986). Researchers have placed electrodes on a limb not being used in the task or on another muscle such as the neck or forehead and general activation theory (Duffy, 1962; Malmo, 1969) predicts that an increase in mental work or stress will be accompanied by a corresponding increase in the EMG tension level. Because there is condiderable variability in the EMG absolute values between subjects, the EMG, to date, has not been considered a simple, diagnostic measure of mental workload (Jex & Allen, 1970; Spyker et al., 1971).

Like performance-based measures, physiological measures give relative measures of mental workload. Increases in one measure, such as heart rate, P300 latency or P300 amplitude as a function of task or

effect is that noise can distract; the other effect is that noise can arouse the operator. If noise acts to arouse the operator, one might expect improved reaction times and better visual-motor performance under noise stress compared to the ambient, noise-free environment condition.

Subject performance under acceleration stress is a function of the $+G_z$ level and task difficulty. Regardless of the task difficulty, as sustained acceleration levels begin to approach man's G tolerance, the human must expend all of his energy and attention in maintaining consciousness and cannot perform a concurrent visual-motor task. In general, for those G levels (less than 9 G_z) up to man's acceleration tolerance level, the human can share his resources that he must expend in maintaining eye level blood pressure and consciousness with those resources required in performing a visual-motor task.

From the review of the workload, noise and acceleration performance literature, relatively little data exist concerning the effect of biodynamic stressors on workload. In addition, because of differences across studies, no capability exists to compare effects of the stressors on the range of performance. What is needed are systematic experiments to determine the effect of sustained acceleration and noise on human performance and workload, with noninvasive physiological parameters measured and correlated to performance and to both subjective and objective measures of mental workload.

physical stressor can be calculated and used to compare against another task or stressor. A 20% increase in heart rate cannot be equated with a 20% increase in mental workload, however, if one task causes a 20% increase and another task under the same condition causes a 5% increase, one can argue that the former task imposes higher mental workload. In addition, these increases, or decreases, in physiological measures are most likely nonlinear.

In summary, mental workload refers to the demands imposed by the system on the operator's capacity for processing information and acting on it (Gopher & Donchin, 1986; O'Donnell & Eggemeier, 1986). Various methodologies exist for measuring mental workload; each has its strengths and weaknesses. Under certain conditions, it is the combination of two or more of these methodologies that best describes the workload of the operator.

Noise and acceleration affect operator performance (Appendix E). Such changes in performance can be interpreted or perceived as increases in mental workload. In order to understand the effect of physical stressors on mental workload it is worthwhile to review the effects of these stressors on human performance.

Human Operator Performance in Noise or Sustained Acceleration Environments

A number of studies have been performed on humans performing in either a high noise (100 dB) or sustained acceleration (greater than 3G) environment. These studies are reviewed in Appendix E and summarized here.

Noise stress appears to have two distinct effects on humans. One

III. RESEARCH PLAN

The principal objective of this research was to determine the effect of biodynamic stressors on human mental workload and performance. In view of the described status of workload research it was decided to measure mental workload with techniques from all three of the basic methodologies used in order to assess their utility in the biodynamic environment.

The utility of all three workload methodologies was evaluated by having the subjects perform a dual task. The dual task accomplished two objectives: 1) it provided the source of workload that was recorded and measured and 2) changes in primary and secondary task performance were, in themselves, measures of mental workload. Dual task performance has been found to be a sensitive, diagnostic tool in determining one's reserve processing capacity (O'Donnell & Eggemeier, 1986).

Prior to developing the dual task, comprised of primary and secondary tasks, the limit and extent of noise and acceleration exposures were defined and an experimental design was developed. The desire was to be able to find differences in subjects' mental workload as a function of increasing task difficulty and increasing stressor and to verify these changes, statistically.

Selecting the Stressors

The typical Air Force or Navy pilot is subjected to a number of biodynamic stressors including heat, cold, vibration, noise, acceleration

and fatigue; he must be able to perform in these stressor environments. Sustained acceleration was selected as one stressor for investigation because it is, perhaps, the most typical environment in which the fighter aircraft pilot must perform. During air-to-air engagements and air-to-surface weapons delivery, pilots spend important time periods at levels greater than 1G. Several researchers (Gillingham et al., 1985) have determined that during mock air combat tactics exercises involving the F-5, F-16 and F-16 aircraft, these latter two aircraft spent on the average, 20 seconds per engagement at or above 5G. Mean engagement durations were 60 seconds. Based upon these results, one minute periods of performance under sustained acceleration were considered representative for this research. Maximum acceleration levels for the subjects were based on the relaxed G tolerances of the subjects rather than their maximum straining, protected G tolerances. The reasons for using the relaxed G tolerances rather than the protected, straining G tolerances of subjects is explained under experiment II in the Methods section.

Noise stress was selected as an operationally relevant stressor, because it is present in all aviation jobs. Noise levels as high as approximately 120 dB A-weighted noise level have been recorded in the cockpit of an F-16A aircraft cruising at 5000 feet and 488 knots indicated airspeed with the environmental control system on, or the defogger on maximum speed (Hille, 1979). The helmet (HGU 26/P with custom helmet liner) effectively suppresses this cockpit noise level approximately 20 dB A-weighted. Noise levels ranging between 90-120 dB A-weighted are not uncommon in the F-16A cockpit (Hille, 1979). Since maximum noise exposures approach 100 dB A-weighted measured at the ear

of pilots of these high performance aircraft and Air Force Regulation (AFR) 161-35 (Aerospace Medicine: Hazardous Noise Exposure) states that more than 30 minutes/day exposure to 100 dB A-weighted noise can result in permanent hearing loss, it was decided to select 100 dB A-weighted as the upper limit of noise exposure for human subjects for this research. Levels higher than 100 dB A-weighted noise would impose exposure limitations of less that the 30 min/day on the subjects which would have been impractical and unrealistic.

In order to be able to compare the upper limits of the acceleration and noise exposures with baseline, or no stress, levels it was decided to have ambient conditions. In the case of noise exposures, ambient was defined as a "no noise" (low noise) condition in the centrifuge cab with the subject wearing a headset but with no noise generated in the headset. The ambient noise level in the cab was measured to be approximately 60 dB; because the headset attenuated the cab noise approximately 20 dB, ambient noise level at the ear is defined as 40 dB A-weighted. For acceleration exposures, the ambient condition was the baseline, or minimum rotating, acceleration of the centrifuge (1.4 G_z). Medium stressor exposures were also selected in order to give three, rather than two levels of stressor for analysis.

The addition of a medium stressor level for analysis purposes gave insight into the action of the stressor at other than the extreme limits. The medium stressor level for noise was selected as 90 dB A-weighted; medium acceleration stress was selected as 1 G less than the maximum relaxed subject and tolerance. These medium levels were based on best estimates by the researcher as providing nominal stressor conditions.

Development of a Performance Task

The tracking task described by Repperger (1984) and used extensively in centrifuge studies at the Armstrong Aerospace Medical Research Laboratory was selected as a primary performance task (Figure 2). The compensatory tracking task has been shown to be sensitive to the effects of G stress (Burton & Shaffstall, 1980; Perez, 1986; Repperger, 1984; Rogers, 1973). Subjects tracked a vertically moving target aircraft and attempted to place the pipper (Figure 2) directly over the aircraft as it moved in an unpredictable fashion on the display. The control stick controlled the movement of the pipper. A secondary task for the subjects to perform in addition to the primary task was selected because it is an effective means for increasing the difficulty of the required performance and it provides a measure of mental workload. As the secondary task performance degrades while maintaining primary task performance, one can relate the degraded performance to a decrease in reserve processing capacity and an increase in mental workload. Because it was desirable to have a secondary task that was operationally relevant, such subsidiary tasks including the audio "oddball" (Gopher & Donchin, 1986) or recalling letter sets were rejected. What was selected was a relevant secondary task.

Subjects monitored a Radar Homing and Warning Display (Figure 2) in which various symbols appeared and disappeared just to the right of the pipper and the subject used short-term memory to retain and act upon the various targets and "threats." This task tapped cognitive resources of the subjects and was accepted by the centrifuge subjects as face valid. Radar Homing and Warning Displays (RHAW) are located on the instrument

panels of fighter aircraft and help the pilot track and monitor friendly and threat aircraft through the use of radar. The subjects' interaction with this task was implemented such that no excessive manual operations were required, such as pushing buttons with the non-tracking hand. Such manipulations could have possibly been confounded by accelerative forces and the objective of this research was to observe the effects of acceleration on the cognitive skills of the subjects. The secondary task was implemented via the trim switch already located on the force control stick used by the subject for tracking.

During a pilot study (described in Appendix D), two levels of difficulty for the primary tracking task and two levels of difficulty for the secondary task were selected. Each of these levels were incorporated into the dual task conditions and also into primary task-alone and secondary task-alone conditions. As explained in Methods and Materials, combinations of these factors resulted in eight task conditions.

Development of the Experimental Design

An experimental design was developed as part of the research plan to incorporate the performance tasks and stressors, such that all performance tasks were performed at all stressor levels. This gave a range of effects of the stressor on the task and resulted in a range of measures of mental workload.

In order to establish confidence in the results, as many qualified subjects as possible were used. Because all subjects had to be members of the Sustained Acceleration Stress Panel, the maximum number of subjects available during this research was 10. Nine subjects

participated in the study. Nine subjects completed experiment I; eight completed experiment II. The 95% confidence intervals and least significant differences discussed in the statistical methods section are based on nine subjects for experiment I and eight subjects for experiment II. Subjects performed, on the average, for one hour per day, including instrumentation and check-out time.

Because subjects would become fatigued if they were required to perform for more than one hour at a time and fatigue was not one of the variables investigated in this research, total subject performance per day was limited to one hour. These relatively short performance periods with breaks between exposures should have minimized any fatigue effects. In developing the experimental design, there were two stressors (noise and acceleration), three levels of stressor (low, medium, high), three primary tracking task conditions (0, $1/S$, $1/S^2$) and three secondary task conditions (0,2,4 targets). Since the no plant-no target condition was not evaluated in the presence of the stressor, this factor was not evaluated, resulting in eight tasks. In order to assess the effects of the stressors independently it was decided to have two experiments. The purpose of the first experiment was to assess the effects of noise on mental workload and the purpose of the second experiment was to assess the effects of sustained acceleration on mental workload.

Design of Experiment I - There were 27 possible combinations of primary task, secondary task and noise level in the factorial design selected for this experiment. Because the no plant-no target condition was not conducted in the three noise levels, 24 combinations of tasks and stressor were developed (Table 1). The goals of this design were

1) to present the noise levels in combination with the primary and secondary tasks in a balanced fashion, with no two noise levels experienced twice in a row (in order to preclude any detrimental effects of two back-to-back 100 dB exposures), 2) to treat all noise levels as equally as possible and, 3) to give an even distribution of the simple secondary task-alone condition among the 24 combinations, giving subjects a mental break during the experiment. The 24-one minute combinations with a 30 second break in between each combination resulted in a 35 minute experiment with subjects exposed to 100 dB A-weighted noise for only eight minutes/day. This was well within the 30 minute exposure maximum allowed in AFR 165-35, explained previously. Subjects trained on the 24 combinations over several days; each subject practiced on the 24 combinations/visit. If their scores were within 5% of the previous day's score, they began actual data runs the subsequent day. No subject took more than four practice sessions for training to this 5% criterion.

Subsequent to training, subjects completed two data collection days performing all 24 combinations (Table 1). Their results over the two data days were then averaged to arrive at means for all 24 combinations. Analysis of the resulting data is discussed in the Methods and Materials section.

Design of Experiment II - The same philosophy from experiment I was carried forward to experiment II. No two G levels were experienced back-to-back, all G levels were treated equally in terms of combinations and there was an even distribution of the simple-to-perform secondary task-alone condition, in order to give the subjects a mental rest. The

24-one minute combinations were split over a two-day period in experiment II (Table 2) in order to reduce the possibility of fatiguing the subjects. Subjects were given a one minute break between acceleration exposures in order to allow heart rates and other physiological variables to return to a resting level. Because these were relaxed subjects, heart rates did return to normal within 60 seconds after each exposure. All subjects received at least one training session under acceleration; nine one-minute tracking exposures were given with three at baseline, three at low G and three at high G. Once the experiment started, each subject experienced 12 exposures plus 11-one minute breaks for a total of 23 minutes/experiment day. Subjects entered the experimental design in either group 1 or group 2 (Table 2) and started with a low or medium G level and not a high G level. This gave the subject a "warm-up" to the high G condition which placed the subject at or near his physiological limit to relaxed G tolerance. The subject then progressed either forward (F) or in reverse (R) order from this combination. This sequence is explained further under Description of the Experiments in the Methods and Materials section.

Selection of Mental Workload Measures

All three of the widely used mental workload methodologies including subjective, performance and physiologically-based measures were evaluated. The objective was to determine how well each methodology agreed in the stressor environment and whether or not stressors affected each methodology in the same way. All three of the methodologies are well-founded in the one G, noise-free environment but their utility in the "stressor" environment remains, essentially,

unproven.

The subjective measure selected was the SWAT. SWAT was selected because there exists a wide data base on its use under a variety of both normal and abnormal conditions (Reid & Nygren, 1988). In addition, the experimental design lended itself conveniently to the concept of the SWAT, with subjects providing a SWAT rating between the 24 trials.

Performance-based methodology selected included both the primary and dual tasks. These weidely used measures have been relatively successful in determining reserve processing capacities in subjects (e.g. O'Donnell & Eggemeier, 1986). Performance-based measures included primary tracking task error score and secondary task performance on the RHAW display (percent hits). Reaction time is another performance-based measure that provided an index of processing load in the subjects. Reaction time and a real-time form of the reaction time or man-machine response time (MMRT) were also recorded. MMRT is explained in Appendix B.

Physiological measures selected included those which have been widely used and are nonintrusive and relatively easy to record. The intent was to observe changes in these measures as a function of increasing mental workload and to equate increases in heart rate, for example, to increases in SWAT or increases in performance-based measures such as error score. Physiological measures recorded under noise exposures included heart rate, P300 latency and amplitude, total eye blinks and blink duration, mean arterial blood pressure and forearm EMG. Physiological measures recorded under acceleration exposures included heart rate, P300 latency and amplitude, total eye blinks and blink

duration, forearm EMG, percent arterial oxygen saturation and percent temporal artery blood flow velocity. Four of these measures, (EKG, EOG, EEG or P300 and EMG) were recorded and analyzed on the Neurological Workload Test Battery (explained and pictured in Appendix C).

Selection of Stressful Environments

The expermental design was based on three levels of stressor. The extreme limits of the stressor were based on typical cockpit exposures and AFR 161-35 in the case of noise exposures (40 dB, 90 dB & 100 dB) and on the relaxed G tolerances of the subjects (1.4 G_z, 2.75 G_z & 3.75 G_z) in the case of acceleration exposures. The rationale for using the relaxed G tolerance of the subjects rather than the straining tolerance was 1) electrodes recording EEG, EOG, EKG, and EMG would be less likely to be contaminated with muscle artifact due to subject straining and, 2) the effect of sustained acceleration on the human without any countermeasures (e.g. anti-G suit or straining maneuver) could be established. In addition, as a first attempt to record mental workload measures under acceleration stress, a conservative approach to stressing the subjects was taken. Future studies will be directed toward recording physiological measures from active, straining subjects under high (greater than 4G) acceleration stress. The technique for establishing the relaxed tolerance is explained in Methods and Materials.

Protocol

The following protocol was followed by subjects participating in these experiments. The following outline is an example of the protocol followed by subjects during the acceleration phase.

I. Instrumentation of the subject and physical exam

A. Subject arrives for experiment

1. Undresses and dons flight suit

2. Physician checks diet and blood pressure of subject

B. Principal investigator and medical technician instrument subject

C. Subject debriefed by Principal Investigator about what the subject will be doing

II. Subject insertion in the cab and checkout

A. Centrifuge floor crew (technicians) insert subject into the centrifuge cab, strap subject in and connect instrumentation leads to appropriate amplifiers

B. Subject is allowed to practice tracking for five minutes while signals from the centrifuge into the medical monitor room are verified

C. When the subject, principal investigator and physician are ready, data collection begins

III. Data Collection

A. Subject is told in advance what task he can expect and at what G-level

B. The neurological workload test battery operator initiates recording with the onset of the 60 second task presented to the subject

C. The subject experiences 12-60 second tasks with a one minute rest in between each exposure. (Subjects returned another day to complete the other 12 exposures)

D. Subsequent to each exposure the subject gives a SWAT score

E. The subject's performance score (tracking error score and number of targets hit) is presented on the crt 15 seconds prior to the start of his next task

F. After the subject has completed all 12 exposures he is removed from the cab and returns to the medical exam room.

IV. Subject debriefing and physical exam

A. The physician examines the subject subsequent to the data collection and all electrodes are removed

B. The subject's next visit to the centrifuge is scheduled and the subject leaves

In summary, a factorial design was selected with subject, task and stressor as the factors. Two stressors were selected for comparison reasons and the stressors were evaluated at low, medium and high levels in order to give three points for analysis. The experimental design was based on all subjects completing all twenty-four randomized combinations of primary and secondary tasks such that no two stressor levels or tasks were presented back to back. Workload measures selected were based on the three widely used methodologies and those measures which have been shown to be sensitive and diagnostic.

Analysis of Data

After the data were collected, means and standard deviations of all of the variables were calculated across task and stressor and these numbers were analyzed via analysis of variance (ANOVA) with task and stressor as fixed factors and subject as a random factor. The least significant difference (LSD) procedure (Daniel, 1983) was used to determine pair-wise differences for task, stressor, plant and target.

This procedure uses t-tests with a .05 per comparison error level. The means were then plotted with 95% confidence interval bars in order to give a picture representation of the LSD procedure and to give the reader the ability to see, pictorially, significant differences in the means as a function of stressor or task difficulty. These procedures are discussed more thoroughly in the Statistical Methods section.

IV. METHODS AND MATERIALS

Description of Experiments

Pilot Study

A pilot study was conducted to select the performance tasks for the study (Appendix D). The criteria for selection of the tasks were that the tasks should be short in duration, demanding, easy to score and face valid. The pilot study was necessary to define the range of tasks and to select the workload measures to be used in the research. The pilot study resulted in the selection of two levels of difficulty for a secondary task (two and four targets) and two levels of difficulty for the primary tracking task (1/S or velocity plant dynamics and $1/S^2$ or acceleration plant dynamics). When combined with targets-alone and tracking-alone conditions, eight tasks resulted. These tasks are described below under Description of the Performance Tasks.

Experiment I - Noise Exposures

The objective of experiment I was to have subjects perform the eight tasks selected from the pilot study while exposed to three different levels of noise stress (24 combinations of task and noise) and to determine the effect of noise on workload measures. Nine subjects participated in experiment I and all 60 second task exposures were performed in the cab of the centrifuge (Figure 1). All subjects had normal hearing audiograms as determined by examination with a TA-20 Automatic Audiometer. Pink noise, which is characterized by equal energy per octave, was generated by an audiometer and transmitted

to the subject via a headset. Each subject completed two days of 24 combinations (Table 1) with a 30 second rest in between combinations. All combinations were randomized such that no two high noise levels were experienced back to back (Table 1). Referring to Table 1, on days 4 and 5, subject 1 began data collection on Day 1 and started with combination 1 and progressed through combination 24 in the forward (F) direction. On Day 2, he started with combination 24 and progressed through combination 1 in the reverse (R) direction. The ambient/no noise condition was evaluated by leaving the audiometer turned off with no noise coming through the headset. This resulted in an approximate 40 dB A-weighted sound level between the headset and the subject's ear, as explained in the Research Plan section. Mean SWAT, tracking error scores, percent targets hit, reaction times to targets, arterial blood pressure, heart rate, total eye blinks, eye blink duration, P300 amplitudes and latencies to target aircraft flashes and to threat targets as well as tracking forearm EMG were computed as a function of noise and task for experiment I and reported in the Results.

Experiment II - Acceleration Exposures

The objective of experiment II was to have subjects perform the eight tasks selected from the pilot study while exposed separately to three different levels of acceleration stress (24 combinations of task and acceleration) and to determine the effect of sustained acceleration on workload measures. Eight of the nine subjects from experiment I completed experiment II. All subjects wore headsets which effectively reduced cab noise almost 20 dB. The same 24 combinations used in experiment I were followed in experiment II, however, acceleration

stress replaced noise stress such that high (3.75 G_z), low (2.75 G_z) and baseline G levels replaced 90 and 100 dB A-weighted sound levels and ambient noise conditions (Table 2). Furthermore, the 24 combinations were then subdivided into two groups (1 and 2) and then randomized with the constraint that no factor levels were experienced back-to-back.

The reason the 24 combinations were divided into two groups (Table 2) was so that no subject would experience more than twelve acceleration exposures/day, with four of these at the subjects' relaxed high G tolerance level. Referring to Table 2, subject 1, for example, began his Day 1 data collection in group 1, starting with combination 12. He progressed forward (F) in the combinations such that he experienced combinations 12, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11 on Day 1 and then on Day 2 he started in group 2 with combination 8. He progressed in the reverse (R) direction starting with combination 8 such that he experienced 8, 7, 6, 5, 4, 3, 2, 1, 12, 11, 10, and 9 to complete his two data days. There was a one minute rest between each trial to allow the subject to give a SWAT rating, to present him with his performance score and to allow the subject's heart rate to return to a baseline or resting level. The performance score was presented to each subject following each trial in order to give the subject feedback on his performance and to help keep him interested and involved with the study. This technique was found to be beneficial in a previous workload study on the centrifuge (Albery, Ward & Gill, 1985).

Although acceleration was the stressor during experiment II, subjects were instructed to relax as much as possible throughout all exposures. By relaxing, two objectives were accomplished; (1) the pure

effect of sustained acceleration on each subject unconfounded by subject straining could be observed and (2) all physiological recordings were uncontaminated, as much as possible, by muscle strain artifact. Relaxed G tolerance for each subject was established on a day prior to data collection. Subjects' G tolerances were established via the widely-used light bar method (Crosbie, 1984) whereby subjects experience increasing levels of acceleration in a step-wise fashion until they lose peripheral vision outside of a 60° cone.

The subject sat in the centrifuge cab (Figure 8) and viewed a semi-circular light bar 27" away and embedded with a series of light emitting diodes (LEDs) spaced 1.5° apart. Bilateral pairs of LEDs were illuminated and controlled by the subject as he deflected the control stick fore/aft. While attending to a central LED, the subject pulled the stick aft and could illuminate the bilateral pair of LEDs at the far border of his peripheral vision. The subject could actively track the extent of his peripheral vision by controlling the deflection of the control stick and, thus, the position of a bilateral pair of illuminated LEDs.

As acceleration increased from 1 G, upper torso blood was pooled into the lower torso of the subject, eye level blood pressure dropped, peripheral vision was diminished and the subject deflected the stick fore, moving the LEDs toward the center of the light bar. Loss of peripheral vision was established at 60°; when the subject moved the LEDs into this 60° cone, the G tolerance was recorded at that particular G level and the centrifuge was returned to the baseline (1.4 G) level.

During G tolerance trials, each subject experienced a 30 second

2.5 G_z exposure while tracking his peripheral vision. If he did not lose peripheral vision into the 60° cone defined by the light bar, he rested one minute and progressed to the next acceleration level, 3.0 G_z. This 0.5 G_z increase procedure was repeated until a G level was reached at which the subject moved the LEDs into the 60° cone.

The subjects' G tolerances for experiment II are listed in Table 3. The average relaxed high G tolerance was 3.75 G. This compares well with relaxed G tolerances from the literature (e.g. Crosbie, 1984; Gillingham, 1974). The medium G level used during experiment II was one G less than the subjects' high G tolerance level and was selected because it was a level halfway between the high and baseline G level. Baseline G levels (1.4 G) were the same for all subjects.

After establishing the subjects' G tolerance, the subject received on the same day nine-60 second training exposures in the centrifuge. Three of these randomly selected combinations were at baseline, three were at their medium tolerance level and three were at their high G tolerance level. Over the two data collection days, each subject experienced the eight tasks at their high G tolerance level, at one G less than their high G tolerance level and at baseline G.

Subjects

The subjects for experiments I and II were all members of the Sustained Acceleration Stress Panel. A total of nine male subjects, mean age 27, participated in both experiments. Eight of the nine subjects completed experiment II and all nine subjects completed experiment I. All subjects were right-handed, had 20/20 correctable vision and were tested for normal hearing. There were no complaints

received from the subjects concerning the quality of the visual display. During the SWAT card sort, these nine subjects tended to fall evenly into three categories; three of the subjects tended to emphasize the psychological stress dimension in their sort, three emphasized mental effort and the other three, time load. Because of this even distribution and a high Kendall's coefficient of concordance, a general group solution (Reid & Nygren, 1988) was used to scale all nine subjects' ratings. The explanation and justification for the group solution is not discussed here, but rather, in the SWAT User's guide (Reid, Potter & Bressler, 1988). No further analysis of the grouping of the subjects' SWAT ratings was performed.

Subjects were motivated to perform at their best. A "Top Gun" trophy was awarded to the subject who had the lowest error scores and best secondary task performance for both experiments I and II. The incentive appeared to be successful in maintaining a high level of performance in all subjects.

Subjective Ratings and Instructions

Physiological variables to evaluate workload were recorded on the equipment described, below. Performance-based measures of workload, such as tracking error scores and hits and misses of targets in the secondary task were recorded on the centrifuge computer (Figure 3). Subjects' subjective ratings were voice recorded after each noise or acceleration exposure. SWAT ratings were used to obtain a psychological assessment of mental workload for each exposure. The three dimensions of time load, mental effort and psychological stress were divided into high (3), medium (2) and low (1) ratings; each subject gave a SWAT

rating immediately after each noise or acceleration exposure. These ratings were then converted into one point on the overall 0-100 point scale that had been previously developed via conjoint analysis to obtain one number for each exposure for each subject (Reid, et al., 1988).

During those tasks where primary tracking-alone was being evaluated, the target aircraft flashed periodically to trigger the NWTB and subjects were instructed to count and to report the number of times the aircraft flashed during the 60 second exposure. These tasks were not, strictly, primary task alone as explained under the next section, Description of the Performance Tasks. During dual performance tasks, where subjects tracked and attended to the secondary task, subjects were instructed to maintain their best performance on the primary task and then to do their best on the secondary task with <u>any spare mental processing capacity or time they had available</u>. Because the composite error score used in computing the subjects' overall error score was based on both the primary and secondary task scores, subjects tended to treat the tasks almost equally. Composite scores were computed by a method developed by the researcher by taking the subject's tracking error score (for example, 20) and multiplying it times the ratio of threat targets displayed during an exposure (such as 14) to the threat targets effectively countermeasured, or hit (such as 7). Such a result would give the subject a composite score of 20 x 14/7 = 40 for one exposure. Subjects were also instructed to give their SWAT rating within 15 seconds after each exposure and prior to the displaying of performance scores on the crt for each trial attempted; this was done in order to preclude any influence of the subject's knowledge of his performance

score in his arriving at a SWAT rating for the trial. During all trials and exposures, subjects were instructed not to talk and during experiment II, subjects were instructed not to strain against the acceleration stress. Subjects were given knowledge about the specific performance task and stressor level prior to each trial or exposure. This was done since the subject would have most likely known within the first ten seconds which combination he was performing, anyway.

Description of the Performance Tasks

The primary task consisted of a computer-generated target aircraft moving unpredictably in the vertical direction, only; the secondary task was a modified Radar Homing and Warning (RHAW) display (Figure 2). The primary task was a compensatory tracking task in which the object was to null the error between the vertically moving aircraft and the pipper (Figure 2). During the pilot study, three different types of control stick dynamics for tracking the vertically moving aircraft were evaluated in order to develop a wide range of task difficulty and mental workload. These types of dynamics included a pure gain (K) plant designated P1, a velocity (1/S) plant designated P2 and an acceleration ($1/S^2$) plant designated P3. These three plant conditions provided a varied relationship between the deflection of the joy stick and the movement of the pipper.

These tracking dynamics have been found to elicit a wide range of tracking performance from subjects (Repperger, 1984). When the subject had pure gain control (K), a displacement of the control stick caused the pipper to move instantly in the direction of the deflection. This was a step-wise type of movement in that the pipper moved from point to

point, almost instantaneously. When the subject had first-order control (1/S), constant displacement of the control stick caused the pipper to move at a constant velocity in the direction of the movement. Under the more difficult second-order control conditions ($1/S^2$), constant displacement of the control stick accelerated the pipper's movement. The difficulty of the tracking task could be increased by changing the forcing function, or speed, of the target aircraft. A forcing function of 1 with either the P1, P2 or P3 plant created a slowly moving target, fairly easy to track; a forcing function of 5 with either the K, 1/S or $1/S^2$ plant resulted in a very responsive target, almost impossible to track accurately. These plants and forcing functions were modulated and evaluated by subjects during the pilot study.

Secondary task (RHAW) difficulty could be modulated by changing the number of threat targets (from 1 to 2 or 4) displayed randomly among the five nonthreat targets (Figure 2). These threat and nonthreat symbols were generated and displayed at the approximate rate of one symbol/second. Threats appeared approximately 20% of the time. There was no specific human factors related reason for the design of the symbols; it was decided not to make them obvious (such as arrows pointing left, right, up or down) but to make them somewhat nondescript such that the subject had to perform some mental processing.

Eight tasks, or combinations, were selected from the pilot study to carry forward into Experiments I and II. The eight tasks are described below:

(1) <u>No-tracking with two threat targets (0-2)</u>: This task was selected as an easy activity wherein the target aircraft remained stationary and

only two threat targets appeared among the five nonthreats. The two targets, randomly generated, always required the up or down thumb action to deliver the countermeasure (Figure 2). The up or down thumb action was selected because it was the easiest thumb movement for the subjects to make. The purpose of this task was to obtain baseline data on the secondary task.

(2) No-tracking with four threat targets (0-4): This task was the same as number 1, above, but employed all four threat targets (Figure 2).

(3) Simple, Velocity (1/S) tracking with no targets (1/S-0): This task was also simple for the subjects and provided baseline tracking data on the primary tracking task. This task was not truly single task control. There was a nonintrusive subsidiary task the subjects had to accomplish while performing this particular task, and that was to count to themselves the number of times the target aircraft flashed during the trial or exposure. The aircraft flashed approximately every 3.5 seconds (approximately 20% of the exposure time) during tasks 3 (1/S-0) and 6 ($1/S^2$-0) in order to evoke a response for recording on the NWTB since there were no targets present during these tasks to evoke the response. Otherwise, there would have been no P300 data for the 1/S-0 and $1/S^2$-0 tasks for comparing to the other tasks.

(4) Simple, Velocity (1/S) tracking with two threat targets (1/S-2): This task was a dual task in that the subject had to track as well as attend to the RHAW display. The two targets were countermeasured by the up and/or down thumb action.

(5) Simple, Velocity (1/S) tracking with four threat targets (1/S-4): This task was the same as number 4 but employed all four threats.

(6) Difficult, Acceleration ($1/S^2$) tracking with no targets ($1/S^2$-0): This task was the same as that described in number 3, above, but employed the more difficult to control acceleration plant dynamics.

(7) Difficult, Acceleration ($1/S^2$)tracking with two targets ($1/S^2$-2): This combination was like combination 4, but employed the more difficult to control acceleration plant dynamics.

(8) Difficult, Acceleration ($1/S^2$) tracking with four targets ($1/S^2$-4): This task was considered to be the most difficult and was similar to task 5 except that the more difficult-to-control acceleration plant dynamics were employed.

Physiological Measurements and Instrumentation

Physiological parameters recorded included the P300, EOG, EKG, EMG, blood pressure (DINAMAP, Model 1255-00006), arterial oxygen saturation (Nellcor N-100), and superficial temporal artery flow (L&M Doppler, Model 501). The latter two measures were recorded during Experiment II, only, since they were sensitive to changes in eye level blood pressures caused by sustained acceleration. Blood pressures were recorded during the last 20 seconds of each 60 second exposure during Experiment I. Blood pressure was not monitored during Experiment II because the equipment was not acceleration qualified. A fully instrumented subject is shown in Figure 6. The layout of the monitoring equipment, subject and computer/machine interface is illustrated in Figure 7.

All subjects were instrumented with electrodes, one for the transient visual evoked response (plus referenced mastoids) located centrally at Cz (International 10-20 electrode system; Jasper, 1958), three for the EKG, (modified Marriott method; Marriott & Fogg, 1979),

two for the EOG plus a ground and three for the EMG (Figure 6). The temporal artery flow velocity transducer has a nickel-sized transmitter and receiver in its head, and is placed over the temporal artery where it is secured by tape and an ace bandage (Figure 6). Medtronic infant monitoring electrodes, "huggables," which are Ag/AgCl, self-adhering and pregelled, were used for EEG and EOG measurements including grounds and reference. NDM Silvon stress test ECG electrodes, Ag/AgCl, which are pregelled and self-adhering were used for EKG and EMG recording and grounds. The SaO2 pulse oximeter transducer was mounted on the bridge of the nose (Figure 6). The EEG signal was amplified 50,000 times with a Gould universal amplifier, model 13-4615-58; bandpass was set at .05 Hz low and 30 Hz high. The EEG was sampled for 1.0 seconds following a trigger signal to the NWTB. All other physiological measures were recorded continuously during each 60 second exposure. The EKG signal was amplified 2000 times with a Gould EKG amplifier, model 13-4615-64. The EOG signal was amplified 2000 times by a Systems Research Laboratories, Inc. amplifier, Model No. 1. The EMG signal was amplified 2000 times with a Gould EKG amplifier, model 13-4615-64. All electroencephalogram leads were shielded and all electrode groups were grounded to insure the safety of the subject.

Equipment

All research was conducted in the Dynamic Environment Simulator (DES) shown in Figure 1. The DES is a 19 foot radius, man-rated, man-operable centrifuge located at the Armstrong Aerospace Medical Research Laboratory at Wright-Patterson AFB, OH. The primary and dual tasks described herein were generated on an Evans and Sutherland

Multi-Picture Graphics System and displayed on a 12 inch diameter crt (Figure 2). Subjects interacted with the display via a force control stick and with a thumb actuated trim switch. Deflecting the control stick moved the target circle or "pipper" (Figure 2) in the vertical direction and moving the thumb trim switch left, right, up or down actuated the countermeasure to the threat (Figure 2). The control stick was controlled by the right hand of all subjects.

Subjects sat in a modified F-16 aircraft seat; eye-to-crt distance was 27". After the tracking task was generated on the graphics system, it was scan-converted using a 525 line, black and white video camera and displayed on the crt in the DES cab. A layout of this configuration is illustrated in Figure 3. A layout of the seat and crt geometries in the DES cab is illustrated in Figure 4.

The DES cab lighting was not as bright as the typical office environment; the subdued lighting made the graphics on the crt easily discernible and allowed for composite video taping of the subject's face and task during data collection. Brightness was measured with a Minolta hand held luminance meter. Typical office environment luminances were found to be approximately 35-40 foot-Lamberts (f-L). The DES cab luminance was 13 f-L. Bright objects on the crt, such as the target aircraft, were as bright as 40 f-L against a background of 1.8 f-L. Normal brightnesses for the aircraft, grid and targets was 3.5-5.0 f-L against a target background of 1.0 f-L. Aircraft and threat symbols subtended an angle of approximately 1° or 60 minutes of arc at the eye of the subject, 27" away. Tracking error scores were derived as the root mean square (RMS) of the error. Tracking error scores represent

degrees error based upon the geometries of the eye-to-crt distance (27") and target aircraft-to-pipper distance (Figure 2). It was determined that a constant 3 1/8" target to pipper distance equated to an error score of 114. This relationship relates to a 1.16° error for a tracking score of 20. Tracking scores herein are reported as whole numbers.

Special equipment (Figure 5) was developed to accurately record the transient visual evoked response and P300 of subjects in experiments I and II. Trigger signals to start the recording of visual evoked responses were generated when a threat appeared or whenever the target aircraft flashed, such as during primary tracking task trials (Figure 2). When the combination included the dual task, the target aircraft did not flash although nonthreat and/or threat targets appeared every 1-2 seconds to the right of the pipper which were sensed, triggered and evoked a response in the subject. These trigger signals and evoked responses were recorded on the (NWTB). A video dot generator (Figure 5) was developed to sense the appearance of the targets or the flashing aircraft on the crt in order to trigger the NWTB to begin recording the transient visual evoked response. Whenever a threat target appeared, the rare event window was filled with a raster, the photocell was energized and the video dot generator sent a logic signal to the NWTB which triggered the onset of recording the one second visual evoked response (Figure 5). Whenever a nonthreat signal appeared, the frequent event window was filled with a raster and the frequent event photocell channel was triggered. The rare/frequent triggers at the bottom of Figure 5 illustrate a typical pattern of triggers observed at the NWTB, with threats/nonthreats occurring once each second and threats occurring

approximately 20% of the time. The evoked responses from nonthreats were recorded but not analyzed for this research. Video transmission delays in the order of 30 milliseconds were eliminated from evoked response analysis by using the photocell pick-up of trigger signals from the crt screen and sending the trigger directly to the NWTB (Figure 5). During noise exposures, 90 dB and 100 dB A-weighted pink noise was generated through a headset driven by a Grason-Stadler Audiometer, Model 1701.

Reaction times were measured from the time a threat target appeared on the subject's screen until the subject actuated the thumb trim switch to deliver a countermeasure. The same video dot generator described above was used to sense the appearance of a threat symbol on the crt screen and it was the start of this signal from the photocell (Figure 5) that was used as time zero in calculating subjects' reaction times to threat targets.

Statistical Methods for Data Analysis

In both the noise and acceleration experiments (Experiments I & II) there were 24 combinations of plant (1, 1/S, $1/S^2$), target (0,2,4) and stressor (Noise: 40 dB, 90 dB, 100 dB or Acceleration: 1.4 G_z, 2.75 G_z, 3.75 G_z). The three stressor combinations with no plant or no target (stressor alone) were not used.

For Experiment I there were two data collection days. Each day a subject performed all 24 combinations once (Table 1). Means for the two replications of each combinatio were taken before analysis to help reduce order effects within a subject. For Experiment II there were two data collection days where subjects performed 12 combinations on Day 1

and the other 12 combinations on Day 2 (Table 2).

In deciding how to model the data the problem of having no data for stressor alone combinations had to be resolved. Since using plant and target as factors in an ANOVA would result in missing cells it was decided to combine plant and target into one factor (called task). The design then included task (see Description of the Performance Tasks) and stressor as fixed factors and subject as a random factor. All of the ANOVA tables (4d-17) are organized as the summary table (4a) below.

Table 4a. ANOVA Summary Table SWAT and Noise

Source of Variation	DF	Sum of Squares	Error Term	F-Value	P-Value
S	8	10811	Error	12.06	.0001
T	7	23472	SXT	26.66	.0001
ST	2	8530	SXST	17.15	.0001
SXT	56	7044	Error	1.12	.2998
SXST	16	3980	Error	2.22	.0081
TXST	14	1522	Error	0.97	.4887
ERROR	112	12555			
TOTAL	215	67913			

S - Subjects

T - Tasks

ST - Stressor (noise or acceleration)

SXT - Interaction between subjects and tasks

SXST - Interaction between subjects and stressor

TXST - Interaction between tasks and stressor

DF - Degrees of freedom

All of the main effects for stressor and comparison of plant and target means (Tables 4d-17) are organized as the summary table (4b) below.

Table 4b. Summary Table for Main Effects of Task and Stressor

Main Effects for Task (LSD=6.1)*

Task	SWAT Means
0-2	9.5
0-4	14.7
1/S-0	16.0
$1/S^2$-0	21.3
1/S-2	25.0
1/S-4	29.4
$1/S^2$-2	33.5
$1/S^2$-4	43.6

(Those means connected by the same line are not significantly different)

*To be significantly different at the .05 level, (LSD = Least Significant Difference), the SWAT means must be greater than or equal to 6.1 units apart.

Comparison of plant and target means were accomplished by taking appropriate contrasts of the levels of task. Mean comparison procedures (Daniel, 1983) which use ranks of the means (e.g. Duncan, Tukey, Newman-Kuels) were not considered since, in theory, the means should be independent, and in this research, the means were not independent (subject was a random factor). The procedures which control the experiment-wise error level (Bonferroni, Scheffe) usually at the .05 level have per comparison error levels ≤ .05 (Daniel, 1983), and it was

felt that by using the LSD procedure, results of pairwise comparisons could be more easily interpreted for the following reasons: (1) a per comparison error level was easier to interpret than an experiment-wise error level which is generally not known but is an upper bound; (2) the .05 per comparison error number can be considered the least amount two means can differ to be considered significantly different; (3) procedures which control the experiment-wise error level at .05 can have very conservative per comparison error levels (task involves 28 pairwise comparisons) which makes a mean difference, that is not quite significant, hard to interpret. (4) 95% confidence intervals for the unknown means of each factor level give a picture representation of the LSD procedure (Figures 9a-36) since the .05 comparison number is equal to 1.4 times the width of half of the confidence interval.

The .05 comparison numbers as shown in figure 9a use only the mean squared error in the error term. Using subject interactions in the error term resulted in very few differences which would be of little value, in terms of interpretation. However, by using only the mean squared error, results pertain only to these subjects and should not be generalized to other subjects.

Missing data resulted for some of the variables, especially physiological measures including the P300 (EEG) and heart rate. In general, less than 3 or 4 data points out of the 24 total data points for a particular subject were lost. If there was a problem in recording a particular variable, such as EKG, the entire record for that subject's 24 combinations was not analyzed, which resulted in a smaller "N." One can see on Tables 19 and 21 that N's for blink duration, EKG, EEG and

EMG were not as high as for the SWAT and performance-based measures. With missing data the F-tests, which use subject interactions as error terms, become approximate. As the number of missing data points decrease this approximation improves.

Due to the missing data and a desire not to assume a linear relationship between variables it was decided to use the Spearman correlation procedure to determine the relationship between the means of the variables (Daniel, 1983). The Spearman correlations, P-values and number of observations (Tables 18 & 20) are organized as the summary table (4c) below.

Table 4c. Summary Table of Spearman Correlation Coefficients, P-value and Number of Observations

	Variable 1	Variable 2.	Variable N
Variable 1	1.0000	-0.40471(a)	0.61619(a)
	0.0000	0.1200 (b)	0.0014 (b)
	24	16(c)	24(c)
Variable 2	.	1.0000	-0.08824(a)
.	.	0.0000	0.7452 (b)
.	.	24	16(c)
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
Variable N	.	. . . .	

Variables - SWAT, Error Score, %Hits, etc.

(a) Correlation coefficient and sign

(b) P-value of that correlation

(c) Number of observations the statistics are based upon

In summary, analysis of variance (ANOVA) allowed for the partitioning and analyses of the total variance in the set of data recorded for this research. The LSD procedure was used to determine the significance of differences in the means since it gives a .05 comparison number to use as a reference. Because the LSD procedure is a liberal method, it is easier to find significant differences in the means. Therefore, the LSD numbers in the Tables (4d-17) and Figures (37-51) represent the smallest difference that can be considered significant. Mean differences close to the .05 number can be interpreted as being borderline significantly different and as differences increase one can be more assured that a significant difference exists. The 95% confidence intervals (Figures 9a-36) allows for a pictorial representation of differences in factor levels.

V. RESULTS

Statistical significance is established at the $P \leq .05$ level throughout the following results. In the ANOVA tables 4d-23, means connected by the same line are not significantly different. Results from noise exposures are presented first followed by results from the acceleration exposures. Results are also illustrated graphically. Figures 9a-22 are plots of the workload measure means versus stressor expressed in terms of 95% confidence intervals. Noise exposure results are at the top of the page and acceleration exposure results for the same workload measure are presented at the bottom of the page, for comparison purposes. Figures 23a-36 are plots of the workload measure means versus task difficulty and are presented in the same manner as figures 9a-22. Figures 37-46 combine the high and low stressor exposures on the same graph and depict the action of the workload measure as a function of task difficulty and stressor. Figures 52-57 combine several of the previous figures on one graph in order to illustrate the different effects of the two stressors on the workload measures.

Effect of noise on mental workload

Subjective Measures

SWAT and noise - Increasing noise stress caused significantly increasing SWAT ratings from the subjects (Table 4d, Figures 9a, 52). Increasing task difficulty also caused significantly increased SWAT ratings from subjects (Figures 23a, 53). The single tasks were judged

to impose less workload than the dual tasks (Figure 23a). F-tests (Table 4d) showed a significant difference among the tasks (P=.0001) and among the noise levels (P=.0001). The noise levels were all pairwise significantly different (means: 40 dB-16.6, 90 dB-23.8, 100 dB-32.0). SWAT correlated positively and significantly with only one performance-based variable, tracking error score (P=.0273). SWAT correlated positively and significantly (Table 18) with heart rate (P=.0134), mean arterial blood pressure (P=.0008) and EMG Standard Deviation (STD) (P=.0001). SWAT correlated negatively and significantly with eye blink duration (P=.0033). There was a significant interaction (P=.0081) between subject and noise (Table 4d). SWAT ratings increased as a function of both noise stress and task difficulty (Figure 37).

Performance measures

Tracking Error Score (Primary task performance) and noise - Noise stress, as it increased from ambient to 100 dB, had no significant effect on primary tracking task performance (Table 5a, Figures 10a, 54). Increasing task difficulty significantly increased error scores on the primary tracking task, with the 1/S velocity plant combination error scores significantly less than those for the $1/S^2$ acceleration plant combinations (Figures 24a, 38, 55). F-tests (Table 5a) showed a significant difference among the tasks (P=.0001) but not among the noise levels (P=.6434). There was significant interaction between task and noise (P=.0007) however, the differences between the 1/S velocity plant and the $1/S^2$ acceleration plant were significant.

Percent Targets Hit (Secondary Task Performance) and noise - Noise stress had no significant effect on performance of the secondary

task, (Table 6a, Figure 11a). Increasing the task difficulty (specifically, when adding two additional threats to the two threat combination) caused secondary task performance to decrease (Figures 25a, 39). F-tests (Table 6a) showed a significant difference among the tasks (P=.0296) but not among the noise levels (P=.4139).

Reaction time (RT) and noise - Noise stress, as it increased from ambient to high levels, tended to reduce subjects' RTs to threat targets (Table 7a, Figure 12a). Significant reductions in RT from the ambient noise condition were observed at both the 90 and 100 dB A-weighted noise levels. Secondary task difficulty tended to increase RT significantly except for the $1/S^2$ acceleration plant conditions (Figures 26a, 40). F-tests (Table 7a) showed a significant difference among the tasks (P=.0003) and among the noise levels (P=.0189).

Man-machine response time (MMRT) and noise - Increasing noise stress reduced the MMRT (Table 8a, Figure 13a), in going from 40 & 90 to 100 dB A-weighted noise levels. MMRT is explained in Appendix B. Increasing task difficulty, especially going from the 1/S to $1/S^2$ plant conditions significantly increased MMRTs (Figures 27a, 41). F-tests (Table 8a) showed a significant difference among the tasks (P=.0001) but not among the noise levels (P=.0888).

Correlation of performance-based measures among themselves and with physiological measures (Table 18) - Tracking error score correlated positively and significantly with MMRT (P=.0019) and EMG STD (P=.0034). Percent targets hit correlated negatively and significantly with reaction time (P=.0001) and EMG STD (P=.0196). RT correlated negatively and significantly with EMG STD (P=.0056) and percent targets hit (P=.0001).

MMRT correlated positively and significantly with tracking error score (P=.0019). MMRT did not correlate significantly with any of the physiological measures.

Physiological Measures

Heart rate and noise - Noise stress had no significant effect on heart rate (Table 9a, Figures 14a, 56). F-tests did not show a significant difference among the tasks (P=.0586) or among the noise levels (P=.2269). Noise level means were (40 dB=73.7 beats per minute, or BPM, 90 dB=74.7 BPM, 100 dB=73.9 BPM). There was a significant difference among the plant conditions with the secondary task, only, combinations showing a significantly lower heart rate than the 1/S velocity plant combinations (means: no tracking=72.9 BPM, 1/S=75.1 BPM, $1/S^2$=74.2 BPM). There was not a significant difference among the target conditions (means: primary tracking, only=74.1 BPM, 2 targets=74.6 BPM, 4 targets=74.7 BPM). Increasing task difficulty caused increasing heart rates (Figures 28a, 57) except within the $1/S^2$ plant condition.

Total Eye Blinks and Blink Duration and Noise - Noise stress had no significant effect on either total eye blinks (P=.5164) or eye blink duration (P=.3469) (Tables 10a, 11a; Figures 15a, 16a). Increasing task difficulty had a significant effect (P=.0001) on total eye blinks (Figures 29a, 43) as subjects tended to blink less during primary tracking and dual task exposures versus secondary task-only exposures. A similar trend (P=.1387) was observed for blink duration (Figures 30a, 44) with blink durations longer for the secondary task, only, combinations and shorter for the primary tracking and dual tasks. F-tests (Table 10a) showed a significant difference among the tasks (P=.0001)

for total eye blinks but not among the noise levels (P=.5164). F-tests (Table 11a) did not show a significant difference among the tasks (P=.1387) or among the noise levels (P=.3469) for eye blink duration.

P300 latency and amplitude and noise

Increasing noise stress had no significant effect on P300 latency or amplitude (Tables 12a, 13a; Figures 17a, 18a). There was a trend of increasing P300 latencies and amplitudes with increasing task difficulty, especially when the secondary task was added to the primary tracking task (Figures 45, 46). F-tests (Table 12a) did not show a significant difference among the tasks for P300 latency (P=.4140) or among the noise levels (P=.6558). F-tests (Table 13a) did show a significant difference among the tasks for P300 amplitude (P=.0187) but not among the noise levels (P=.5675).

Mean Arterial Blood Pressure (MAP) and noise - 90 and 100dB noise levels tended to have higher MAPs than the 40dB level (Table 15, Figure 20). MAPs were significantly higher for the $1/S$ and $1/S^2$ plant conditions than for the 0 plant condition (Figure 34). F-tests (Table 15) did not show a significant difference among the tasks (P=.0944) or among the noise levels (P=.1172).

EMG standard deviation (STD) and noise - Noise stress had no significant effect on EMG STD (Table 14a, Figure 19a). Increasing task difficulty had a significant effect on EMG STD (Figure 33a). EMG STD increased significantly when the secondary task was added to either the $1/S$ velocity or $1/S^2$ acceleration plant tracking-only task. F-tests (Table 14a) showed a significant difference among the tasks (P=.0070) but not among the noise levels (P=.5965).

Correlation of physiological measures among themselves and with performance-based variables (Table 18) - Although heart rate did not correlate significantly with any of the performance-based variables, heart rate correlated positively and significantly with mean arterial blood pressure (P=.0066) and negatively and significantly (P=.0091) with eye blink duration. Neither total eye blinks nor eye blink duration correlated significantly with any of the performance-based variables. Total eye blinks did not correlate significantly with any of the physiologically-based variables; blink duration correlated negatively and significantly with mean arterial blood pressure (P=.0389) and heart rate (P=.0091).

P300 latency and amplitude did not correlate significantly with any performance-based variables. However, P300 latency and amplitude correlated positively and significantly with EMG STD (P=.0098 and P=.0160, respectively). Mean arterial blood pressure (MAP) did not correlate significantly with any of the performance-based variables. MAP did correlate positively and significantly with heart rate (P=.0066) and EMG STD (P=.0256); MAP correlated negatively and significantly with eye blink duration (P=.0389).

Effect of acceleration on mental workload

Subjective Measures

SWAT and Acceleration - As acceleration increased from baseline to medium and high levels, the stressor caused significantly increasing SWAT ratings from the subjects (Table 4e, Figures 9b, 52). Increasing task difficulty also caused significantly increasing SWAT ratings (Figure 23b, 53). SWAT ratings increased as a function of both stressor

and task difficulty (Figure 37). F-tests showed a significant difference among the tasks (P=.0001) and among acceleration levels (P=.0001). The acceleration levels were all pairwise significantly different (means: 1.4 G=12.5, 2.75 G=19.3, 3.75 G=39.0). SWAT correlated positively and significantly (Table 20) with tracking error score (P=.0024) and negatively and significantly with percent targets hit (P=.0205). SWAT correlated positively and significantly (Table 20) with heart rate (P=.0001), P300 latency (P=.0265) and EMG STD (P=.0014).

Performance Measures

Tracking Error Score and Acceleration - Error scores increased with increasing acceleration; error scores for the high acceleration exposures were significantly higher than those for baseline (1.4 G) exposures (Table 5b, Figures 10b, 54). Similarly to noise stress, increasing task difficulty increased error scores on the primary tracking task, with the 1/S velocity plant dynamics combinations scores less than those for the $1/S^2$ acceleration plant combinations (Figures 24b, 38, 55).

Percent Targets Hit and Acceleration - As under noise stress, increasing acceleration stress had no significant effect on performance of the secondary task. There were consistent decreases in secondary task performance in going from one 2 to 4 target conditions except for the 1/S plant condition (Figure 39).

Reaction Time (RT) and Acceleration - Acceleration stress had no significant effect on RT (Table 7b, Figure 12b). As under noise stress, increasing task difficulty tended to increase subjects' RTs (Figure 26b). F-tests (Table 7b) showed a significant difference among the

tasks (P=.0001) but not among the acceleration levels (P=.3056).

Man-Machine Response Time (MMRT) and Acceleration - Increasing acceleration stress significantly reduced the MMRT in going from the baseline (1.4G) to the low (2.75G) level (Table 8b, Figure 13b). MMRT is explained in Appendix B. As under noise stress, MMRTs for the $1/S^2$ acceleration plant combinations were higher than MMRTs for the 1/S velocity plant combinations (Figure 27b). F-tests (Table 8b) showed a significant difference among the tasks (P=.0001) and among the accelerations levels (P=.0410).

Correlation of performance-based variables among themselves and with physiological variables (Table 20) - Tracking error score correlated positively and significantly with MMRT (P=.0001), P300 latency (P=.0026) and with EMG STD (P=.0279). Secondary task performance, percent targets hit, correlated negatively and significantly with reaction time (P=.0077), only. Percent targets hit did not correlate significantly with any physiological variables.

MMRT correlated positively and significantly with tracking error score (P=.0001), only. MMRT did not correlate significantly with any physiologically-based variables.

Physiological Measures

Heart Rate and Acceleration - As acceleration increased from baseline to high levels, the stressor significantly increased subjects' heart rates (Table 9b, Figures 14b, 56). The mean heart rate of the subjects was significantly higher for the 1/S and $1/S^2$ plant conditions than for the no plant condition (Figures 28b, 42, 57). F-tests (Table 9b) showed a significant difference among the tasks (P=.0443) and among

the acceleration levels (P=.0001).

Total Eye Blinks and Blink Duration and Acceleration - Increasing acceleration significantly increased total eye blinks (Table 10b, Figure 15b) and decreased blink duration (Table 11b, Figure 16b). Increasing primary task difficulty reduced total eye blinks (Figure 29b) but had inconsistent effects on blink duration (Figure 30b). Subjects tended to blink less and for shorter durations with increasing acceleration (Figures 43, 44). There was a difference among the tasks (P=.0001) and among the acceleration levels (P=.0184) for total eye blinks (Table 10b) and a significant difference among the tasks (P=.0105) and among the accelerations levels (P=.0017) for blink duration (Table 11b). There was a significant interaction between task and acceleration for blink duration (P=.0212).

P300 latency and amplitude and acceleration - As under noise stress, increasing acceleration stress had no significant effect on P300 latency or amplitude (Tables 12b, 13b; Figures 17b, 18b). Increasing task difficulty had no significant effect on P300 latency or amplitude (Tables 12b, 13b; Figures 31b, 32b). P300 latency amd amplitude did show a trend of increasing with task difficulty, especially when the secondary task was added to the primary tracking task (Figures 45, 46). F-tests (Table 12b) did not show a significant difference among the tasks (P=.2846) or among the acceleration levels (P=.3102) for P300 latency. Likewise, F-tests (Table 13b) did not show a significant difference among the task (P=.3165) or among the acceleration levels (P=.7173) for P300 amplitude.

EMG Standard Deviation (STD) and Acceleration - Acceleration stress

significantly increased EMG STD (Table 14b, Figure 19b). The EMG STD for the high (3.75G) acceleration exposures was higher than the EMG STD for either the baseline (1.4G) or low (2.75G) exposures. As under noise stress, increasing task difficulty had a significant effect on EMG STD, (Figure 33b). EMG STD increased significantly when the secondary task was added to the $1/S^2$ acceleration plant tracking-only task (Figure 33b). F-tests (Table 14b) showed a significant difference among the tasks (P=.0018) and among the acceleration levels (P=.0452).

Correlations of physiological variables among themselves and with performance-based variables (Table 20) - Heart rate did not correlate significantly with any of the performance-based variables, however, heart rate correlated positively and significantly with total eye blinks (P=.0412) and negatively and significantly with eye blink duration (P=.0017). Neither total eye blinks nor blink duration correlated significantly with the performance-based variables. Total eye blinks correlated positively and significantly with P300 amplitude (P=.0145). P300 latency correlated positively and significantly with reaction time (P=.0035) and tracking error score (P=.0026). P300 amplitude did not correlate significantly with any of the performance-based variables. P300 amplitude correlated significantly with P300 latency (P=.0192). EMG STD correlated positively and significantly with reaction time (P=.0037), tracking error score (P=.0279) and P300 latency (P=.0015).

Other Physiological Measures

Percent Temporal Artery Flow Velocity - Acceleration had a significant effect (P=.0039) on percent artery flow velocity with high (3.75 G) acceleration resulting in lower velocities (Figure 22, 36).

F-tests (Table 17) did not show a significant difference among the tasks (P=.3135).

Arterial Oxygen Saturation (SaO_2) - SaO_2 was recorded during the acceleration exposures, only, and the purpose was to obtain an additional (to Temporal Artery Flow Velocity) measure of acceleration stress on the subject. There was no significant effect of task (Table 16, Figures 21, 35) or acceleration on SaO_2 throughout the acceleration exposures.

VI. DISCUSSION

Effect of noise on mental workload

The only significant effects of 90 and 100 dB A-weighted noise in this research on mental workload were reflected in the subjective measure (SWAT), two performance measures (reaction time and MMRT) and one physiological measure (mean arterial blood pressure). The other two performance measures (primary tracking error score and percent hits on the secondary task) were not significantly affected by the noise stress. Likewise, physiological measures including heart rate, eye blink and blink duration, P300 latency and amplitude and forearm EMG were not significantly affected by the increased noise stress.

The reason why the subjective measure of mental workload increased with increasing noise stress is reflected in the analysis of the three components of the composite SWAT score (Table 22). All of the subjects' SWAT ratings were analyzed as a function of noise (Figure 48) and as a function of task difficulty averaged across noise (Figure 50). The psychological stress component, which reflected the effect of the stressor on the subjects' mental workload, increased more than the time load or mental effort components in going from the ambient to high stressor level (Figure 48). The subjects apparently used the psychological stress component to reflect the effect of noise stress on their overall mental workload; the psychological stress component increased significantly from 90 dB to 100 dB, averaged across all subjects.

SWAT ratings as a function of task difficulty averaged across noise exposures resulted in a different trend (Figure 50). As the task difficulty increased, it was the mental effort component that was rated the highest by all of the subjects, especially for the more difficult, $1/S^2$ tasks (Table 22, Figure 50). Time load was rated the lowest of the three components, most likely because the primary and dual tasks were not time-dependent tasks; subjects had fixed performance periods and evidently felt they had adequate time to perform the task. The time load component could be modulated in future research efforts by increasing the speed of the target aircraft and/or rate of presentation of targets for the secondary task. These two factors remained constant throughout this research.

When plotted on the same graph, the low and medium levels of noise stress selected for this research were judged to generate more mental workload for the subjects than low and medium levels of acceleration stress (Figure 52). High acceleration stress was rated higher than high noise stress on the combined SWAT scales (Figure 52). The only significance of this specific result is that the stressor levels selected for this research were fairly well matched in their overall effect on the subjects' mental workload; had 120 dB A-weighted noise or $9G_z$ acceleration stress been selected, the results would have been different. However, more generally, the result suggests that the SWAT scales can be used effectively to compare and equate workload under different stressor conditions.

On the same plot, tracking error scores were higher for

acceleration exposures than for noise exposures (Figure 54). Likewise, heart rates were higher for the acceleration exposures than for noise exposures (Figure 56). One can see that equivalent tracking error scores or heart rates could possibly result from higher noise stress and/or lower acceleration stress (Figures 54, 56). Likewise, other stressors such as heat, cold, vibration could possibly be modulated to produce equivalent effects of tracking error scores or heart rate, for example. Again, a most important indication of the present research is that workload under different stressors and levels of stress can be equated using the above kinds of metrics.

Different workload measures under noise stress gave opposite results. As the noise stress increased, blood pressures increased but reaction time, man-machine reaction time and eye blink durations all decreased. What this result means is that the action of some workload measures is to decrease from some baseline level when workload increases; other measures increase. A good example of this opposite effect of workload measures is the eye blink measure. One would expect to blink less when attending to a visual-motor task if it were possible to miss a critical element of the display while blinking. Thus, increased workload results in a decrease in total eye blinks. Other opposite workload effects were observed under acceleration exposures, discussed later.

Performance-based workload measures affected by the noise stress included reaction times to the targets in the secondary task as well as the man-machine response time (MMRT). Noise stress tended to reduce reaction times to the targets as well as the MMRT; this reduction in

both the reaction and response times is attributed to the alerting cue phenomenon of high noise levels (e.g. Teichner, 1963). Man-machine response time was significantly lower for the 100 dB exposures than for the ambient or 90 dB exposures. Evidently, the high noise stress tended to keep the subjects more alert than the quiet, ambient noise condition.

The only physiological measures significantly affected by the noise stress was mean arterial blood pressure (MAP). MAP increased significantly for the 90 dB and 100 dB exposures compared to the ambient exposures. This increase is attributed to the effect of noxious stimuli on blood pressure observed by other researchers (e.g. Gunn, Wolf, Block & Person, 1972; Obrist, 1963, 1976).

Effect of acceleration on mental workload

Acceleration stress significantly affected measures from all three workload methodologies. SWAT increased with increasing acceleration; performance-based measures significantly affected by acceleration stress included primary tracking error score and man-machine response time. Physiological workload measures affected significantly by acceleration included heart rate, eye blinks and blink duration. Performance-based measures such as percent hits on the secondary task and reaction time to the targets were not significantly affected by the acceleration. The only physiologically-based measures not significantly affected by the acceleration stress were the latency and amplitude of the P300.

Subjective mental workload increased with increasing acceleration stress because of the contribution of the psychological stress component to the SWAT score (Figure 4?). As in the case of noise stress, subjects tended to reflect the increased effect of the acceleration on their

mental workload in the psychological stress component (Table 23). This component increased more than either the time load or mental effort components in going from baseline to the high G level (Figure 49).

As a function of increasing task difficulty, the mental effort component was larger than the time load or psychological stress components during acceleration exposures and, especially, for the more difficult $1/S^2$ tasks. Time load was consistently rated lower than the other two components throughout all noise and acceleration exposures.

For the stressor levels selected for this research, high acceleration generated more mental workload for the subjects than did 100 dB-A weighted noise stress (Figure 52). Had a higher noise level been selected (e.g. 120 dB), both stressors may have been equivalent in terms of their effect on subjectively measured mental workload. When plotted on the same graphs, acceleration effects on tracking error score and heart rate were more pronounced than those for noise stress (Figures 54-57).

Performance-based workload measures affected by acceleration stress included primary tracking error score and man-machine response time. The tracking error score tended to increase as acceleration increased. This increased error is attributed to the effect of the acceleration on the cognitive performance rather than motor performance of the subjects, since the tracking control stick was a force stick, very little deflection was required to effect movement of the pipper on the display (Figure 2). Although the decrease in performance was not significant, a similar effect was observed for the percent hits on the secondary task (Figure 11b). The percent hits dropped from 94.1 to 91.1 (Table 6b)

going from medium (2.75G_z) to high (3.75 G_z) acceleration. Because the secondary task was accomplished by trim switch activation, acceleration should have had little or no effect on this motor activity.

Mean reaction times were less for the acceleration exposures than for the noise exposures. This result is perhaps due to two reasons: 1) order effect, the acceleration phase followed the noise phase and the subjects could have become more proficient and 2) there is evidence that simple reaction time increases under acceleration (Canfield, Comrey & Wilson, 1949); acceleration can serve as an alerting cue.

Man-machine response time was significantly less for the medium acceleration (2.75 G_z) exposures as compared to either the baseline or high G_z levels. No explanation can be given for this result; reaction times to targets under medium acceleration exposures were also less than those under baseline or high acceleration levels (Figure 13b).

Heart rate, total eye blinks and blink duration were the three physiologically-based workload measures that were affected significantly be acceleration stress. The effect of acceleration on the cardiovascular system is well documented; heart rates increase with increasing acceleration stress (e.g. Chambers, 1963; Crosbie, 1984; Gillingham, 1974; Grether, 1974; Little, Hartman & Leverett, 1968). Subjects tended to blink more as acceleration stress increased. Mean total eye blinks nearly doubled under the high acceleration exposures compared to the mean eye blinks observed under high noise stress. This phenomenon is attributed to the physiological effect of acceleration on vision, discussed later. Blink durations tended to be shorter under G stress than under noise stress. This result is also attributed to the effect

of acceleration on vision and not to any cognitive-related phenomenon.

Different workload measures under acceleration stress gave opposite results. As the acceleration stress increased, SWAT, tracking error score, heart rate, total eye blinks and EMG STD all increased; blink durations, percent targets hit on the secondary task and man-machine response time all decreased. These latter three measures' actions were to decrease rather than increase from some baseline level as workload increased. One would expect the percent targets hit on the secondary task to decrease as the workload increased; the subjects had less reserve capacity to attend to the secondary task as mental workload increased. As in the case of noise exposures, some workload measures under acceleration stress gave results opposite to those of other workload measures.

In summary, both noise and acceleration stress resulted in significant effects in at least one or two measures from each of the three workload methodologies. Increases in SWAT scores as a function of stressor were due to increases observed in the psychological stress component of the SWAT score. The acceleration stress selected for this research tended to have a more significant effect on all three methodologies than the noise stress. Each workload measure is discussed in detail, later. One of the objectives of this research was to determine how well the three methodologies correlated. The correlational analysis is discussed below.

Correlational Analysis

A correlational analysis provides the researcher with information regarding the similarities between the action of several different

variables. It is of interest to know if increasing stressor or increasing task difficulty affect the various workload measures; whether or not the workload measures are sensitive to the increased workload. Those measures which do not change significantly with increasing workload should not be disregarded; they may provide valuable information at extreme levels of workload, for example.

For analysis purposes, we want workload measures to correlate significantly. This tells us that whether the measure is subjective, performance-based or physiologically based, its reaction to workload is similar to that of other methodologies. However, because a measure does not correlate significantly with other measures does not mean it is not a sensitive workload measure; the measure may be sensitive to a more specific range of workload than the one it has been subjected to, for example.

Significant correlations were observed across all three workload methodologies. Correlations were usually positive, i.e., those measures which correlated significantly with one another were, generally, in the same direction. As heart rate increased with increasing workload, for example, SWAT scores increased. SWAT correlated significantly with performance-based and physiologically-based variables under either noise or acceleration stress. During noise exposures, SWAT correlated significantly with one of four performance-based variables and four out of seven physiologically-based variables. During acceleration exposures, SWAT correlated significantly with two of four performance-based variables and three of six physiologically-based variables.

Although SWAT correlated highly with performance-based and physiologically-based measures, performance-based and physiologically-based variables did not correlate with one another very well in this study. These methodologies may very well be measuring different aspects of workload, however, such as maintaining performance at some physiological cost. Across noise exposures, performance-based measures correlated significantly with only three of twenty-eight possible combinations with physiological variables. In noise exposures, primary task tracking error score was the only performance-based variable that correlated significantly with SWAT. Across acceleration exposures, performance-based variables correlated significantly with only four of twenty-four possible combinations with physiological variables. In acceleration exposures, secondary task performance (percent targets hit) was the only performance-based variable that correlated significantly with SWAT. Performance-based variables correlated well within the group, with four of nine possible combinations correlating significantly across noise exposures and four of nine across acceleration exposures.

Physiologically-based variables correlated significantly with 11 of the other workload variables. Across noise exposures, physiologically-based variables correlated significantly with only three of twenty-eight possible combinations of performance variables. Those three correlations were with the EMG STD which is a physiological measure, but is not considered a mental workload variable. Four out of seven variables correlated significantly with SWAT, however. Across acceleration exposures, physiologically-based variables correlated significantly with four of twenty-four possible combinations (two of which were EMG STD).

Physiologically-based variables, like performance-based variables, correlated well within the group, with eleven of thirty possible combinations correlating significantly across acceleration exposures and nine of thirty-six possible combinations correlating significantly across noise exposures. Three of six physiologically-based variables correlated significantly with SWAT.

In summary, there were significant correlations among all three workload methodologies under both noise and acceleration exposures. Those measures which correlated significantly are considered to be the better workload measures at least in terms of this analysis; those measures which did not change significantly as a function of increasing workload may be more sensitive under specific experimental conditions, but under the constraints of this research offered little or no insight into the changes in mental workload of the subjects. Because those measures, such as P300 latency and amplitude, did not correlate will with a number of the other measures does not mean they are "bad" measures; on the contrary, if one inspects the action of P300 amplitude as a function of increasing task difficulty (e.g. Figures 32 a, b) one can see significant increases in the amplitude as a function of increasing secondary task targets from two to four. Analyzed across the entire range of task difficulty however, P300 amplitude did not correlate well with other measures.

Significant Interactions

There were significant interactions between task and noise for primary tracking task error score and man-machine response time and between task and acceleration for heart rate and blink duration. While

some of these workload variables were increasing or decreasing at one stressor level, they were doing just the opposite at other stressor levels. Tracking error score increased when the four target condition was added to the two target condition for both the 1/S and $1/S^2$ plants and with 90 dB and 100 dB noise, but decreased under the same conditions at ambient noise levels. This increase is attributed to the effect of noise on tracking performance. Heart rate tended to increase as a function of acceleration and task difficulty, however, heart rate remained the same or even decreased when the four target condition was added to the 1/S or $1/S^2$ plant, compared to the two target 1/S or $1/S^2$ plant condition at high G. At baseline (1.4G) acceleration, heart rates tended to increase under the same conditions, above. One possible explanation is that the subjects did view the $1/S^2$-4 task as the most difficult and when coupled with the high G condition, considered it an almost impossible task to perform. Error scores and percent targets hit were their worst for this combination and perhaps the subjects were under less pressure to do well knowing it was too difficult a task.

Blink duration increased for the $1/S^2$ tasks from 40 dB to 90 dB and 100 dB but decreased under the same conditions for acceleration. This significant interaction is attributed to the effects of acceleration on vision and not task difficulty, per _se_.

In summary, because some workload measures interacted significantly with stressor and task and others didn't does not mean the interacting measures were better workload measures than the others. For the constraints of this research, these measures interacted; under different experimental conditions, these measures may not have interacted. What

is of interest about the significant interactions in this research is the effect of the two stressors on the measures. Acceleration stress tended to increase several measures (heart rate, total eye blinks, tracking error score) while noise stress had little or no effect on these measures. By analyzing the significant interactions, one can determine the different effects increasing stressor or task difficulty had on a workload measure and gain more insight into the response of the measures to increased workload.

The general effects of noise and acceleration on the human operator are that these stressors tend to increase mental workload. Not all of the workload measures followed the same pattern, however. The effect of the stressor and increasing task difficulty on each workload variable evaluated in this research is discussed below.

SWAT

The results of the analysis of SWAT as a subjective measure of workload suggest that with the highly trained subjects in this study, SWAT can be a sensitive workload instrument. SWAT needs no other factor or dimension in order to justify its power as an accurate and reliable indicator of mental workload in the biodynamic environment. One limitation of the SWAT however, is that it provides relative information, as do other measures of workload. As a result, one is restricted in saying only that one task has more or less workload than another. In addition, subjective measures can sometimes be influenced by prior knowledge of the performance task or environment ("this is a high acceleration level so I need to rate it high"). Research is clearly needed to define the degree of influence of factors such as the number and range of task

levels present in a studyor the order effects of the various conditions of the study. Once this aspect of the measurement process is understood then it may be possible to establish a "redline" for workload, a situation where the probability of performance breakdown is increased (Reid & Nygren, 1988).

Heart Rate

Heart rate consistently and reliably correlated with SWAT and other physiological variables of workload, but did not correlate significantly with most of the performance-based variables. Heart rate tended to increase as a function of task difficulty, but did not correlate significantly with primary or secondary task performance across either noise or acceleration exposures. This result does not reduce the overall effectiveness of heart rate as a sensitive measure of workload; a sensitive workload measure might not correlate significantly with primary task performance variables. One example is P300 amplitude. These results provide additional support to the concept that, under certain conditions, heart rate can be considered an index of workload; heart rate increases tracked increases in SWAT, blood pressure and other workload measures. Various researchers (e.g. Blitz, Hoogstraten & Mulder, 1970; Boyce, 1974; Hasbrook & Rasmussen, 1970; Kalsbeek, 1963, 1968, 1973; Krzanowski & Nicholson, 1972; Spyker, Stackhouse, Khalafalla & McLane, 1971; Stackhouse, 1973, 1976) found heart rate to be a reliable indicator of workload.

Total Eye Blinks and Blink Duration

Under noise or acceleration stress, subjects tended to blink less when they were task loaded. This is a logical result since the subjects

had to attend to the tracking or dual task more significantly than to the secondary task alone. It has been observed that approximately once every five seconds, human vision is interrupted for 200-300 milliseconds by an eye blink (Lawson, 1948). This interruption represents approximately 6% of our average viewing time. Total vision, however, is not totally obscured for the entire duration of an eye blink and it has been estimated (Kennerd & Glaser, 1964) that only 3% of viewing time is blacked out by eye blinks. The range of total eye blinks per 60 second exposures throughout this research ranged from 0 to over 60 eye blinks. Blink durations were shorter for the tracking and dual tasks compared to secondary task for noise exposures but did not show the same trend for acceleration exposures. Low and high G levels caused the subjects to blink for shorter durations as compared to 90 and 100 dB A-weighted noise exposures. This shorter blink duration can possibly be attributed to the physiological effects of acceleration on vision; some subjects' eyes teared during high G exposures as lacrimation can be a side effect of high sustained G. Likewise, high G also caused subjects to blink more often than they did at lower and baseline G levels.

As indices of mental workload, total eye blinks and blink duration correlated significantly with only a few physiologically and performance-based variables under noise exposures. Because of the physiological effects of high G on vision, use of these indices for evaluating mental workload under sustained acceleration may be less than effective as it may be difficult to separate the effects of acceleration on vision from the effects of cognitive load on vision. Whether the observed effects were truly due to workload differences or simply

resulted from acceleration changes in motivation, boredom or fatigue (O'Donnell & Eggemeier, 1986) cannot be determined from these results.

P300 Latency and Amplitude

Although the stressors had no effect on P300 latency and amplitude, increasing task difficulty tended to increase P300 latencies and amplitudes. These results can be interpreted within a framework which suggests that the levels of stressors investigated in this research tended not to load-up the human's central processing system. Both P300 latencies and amplitudes increased, sometimes significantly, whenever the secondary task was added to either the $1/S$ or $1/S^2$ plant condition averaged across all noise or acceleration exposures. This observed increase in amplitude may be attributed to the possibility that both the primary and secondary tasks shared the same common visual modality and spatial location in the brain, as postulated by Wickens et al., (1983). The reason why P300 amplitudes increased rather than decreased may be because subjects biased their allocation of resources more toward the visual secondary task than they would have toward an auditority secondary task, which has been found to decrease the P300 amplitude. These results also support the theory that P300 latency is an indicator of the amount of time a subject takes in evaluating a stimulus (Donchin, 1981); reaction times to targets increased as a function of task difficulty (Figures 31c, 31d) just as did P300 latencies (Figures 26a, 31a) averaged across all stressor levels.

The increase in P300 amplitude with increasing tracking difficulty was also observed by Qiyan and Xu (1985) and Wickens, et al. (1983). Wickens, et al. (1983) found that increases in difficulty of the primary

visual task elicited P300's with increasing magnitude. Whereas the P300 amplitude is significantly attenuated by the introduction of a tracking task in concurrence with a counting task (Navon & Gopher, 1979), the reciprocal change in P300 amplitude for visual probes has been attributed to the activation of some information processing activity that is invoked by the appearance of task-relevant events; its amplitude is inversely related to its expectancy (Wickens, et al., 1983).

P300 latencies and amplitudes were the most difficult variables to record and analyze in this research. Because of their low signal strength (means ranged between 6 and 22 microvolts on Figures 46a, 46b) and the problem of sending these amplified signals across the centrifuge slip rings (the electrical interface between on-board the centrifuge and the outside world), P300 processing was difficult, at best. Perhaps the biggest drawback of using it as a potential workload index is the subjectivity involved in selecting the P300 peak. This is no straight-forward task and is fraught with personal subjectivity. Because the performance tasks were of such short duration (60 seconds) and event related potential (ERP) analysis is dependent upon averaging a number of evoked response waveforms, it was decided to attempt to visually evoke a response from each subject at least 10-14 times during the 60 second exposure. 10-14 trials are a relatively low number of trials on which to base a composite ERP in an applied environment; other researchers use 50-100 trials on which to base a composite (Qiyan & Yu, 1985; Wickens et al., 1983). Because of the nature of this research, it was not feasible to obtain 50-100 trials per exposure on which to base a composite, or average, ERP. The range of trials for the 450 ERPs

recorded during all of the exposures was from one to twenty-two ERPs averaged per exposure with a mean of eleven and a standard deviation of three. These ERPs were averaged for each combination or task for each subject.

Composite ERPs were then traced onto paper and arranged three to a page according to task with the ERP from the low, medium and high stressor level arranged from the top to the bottom of the page. This allowed a visual analysis of the ERPs for similar positive peaks and valleys. It was also beneficial to compare ERPs for a dual task (e.g. 1/S-2) with the ERP from the primary task (1/S-0). Many times, a similar positive peak could be identified on the primary task ERP which corresponded to that observed on the dual task ERP. All ERPs were analyzed in this manner, comprising composite records of all subjects' ERPs and analyzing them (selecting the P300 peak) together. This process is explained more thoroughly in Appendix C.

The utility of the P300 as a valuable workload index has been demonstrated in the laboratory (for example Donchin, 1981; Gopher & Donchin, 1986; O'Donnell & Eggemeier, 1986) but has severe limitations in the dynamic application, such as in the centrifuge. P300 recording and analysis in the airborne environment is also a difficult proposition, especially where performance periods are usually short-term and physiological recording equipment is usually constrained by weight and cockpit capacity limitations. New developments in miniature, high-fidelity physiological recorders may improve this situation, but unless a more reliable and less subjective methodology is used for eliciting and analyzing the P300, its utility as a practical tool in dynamic and

airborne applications of indexing mental workload during short-term performance tasks is suspect.

Primary Task Performance

Primary task performance was unaffected by noise stress but deteriorated with increasing acceleration stress. Primary task tracking performance was significantly worse for the $1/S^2$ (acceleration) plant combinations, independent of stressor. Previous researchers (Broadbent & Gregory, 1965; Hamilton & Copemen, 1970), using different tracking dynamics, found that tracking performance improved with 100 dB noise stress. Although error score means improved at 90 dB and 100 dB in this study, these improvements were not significantly better than tracking performance at ambient noise levels (40 dB). The increased error scores under increased acceleration stress confirms findings by previous researchers (Loose et al., 1976; Repperger, 1984; Warrick & Lund, 1946).

Mean tracking error scores increased with the addition of the secondary task averaged across all noise or acceleration exposures, but not significantly. This result would tend to support the fact that subjects followed the original instructions to maintain primary task performance at all costs and to attend to the subsidiary task with reserve processing capacity, only.

Mean error scores increased as a function of increasing acceleration during the acceleration phase. This decrement in tracking scores is attributed to acceleration effects which include visual as well as motor problems. Several subjects' vision nearly collapsed to a blackout condition at the higher G levels and early in the exposure. As a result, tracking task performance suffered. This can be seen graphically

(Figure 47) as the subject's eye level blood flow and pressure dropped off significantly (pulsatile Doppler temporal artery flow velocity) during a 4.5 G exposure. In summary, the primary task selected for this research was unaffected by the noise stress but resulted in increasing errors as acceleration stress was increased. This increase in tracking error score with increasing acceleration is due to acceleration effects on eye level blood pressure, vision and, perhaps, the increased weight of the tracking arm under G.

Secondary Task Performance

By modulating the number of targets presented on the Radar Homing and Warning display, secondary task difficulty could be varied. Primary task performance did not significantly degrade as secondary task difficulty was increased, however. Subjects tended to work harder to maintain primary task performance as the secondary task difficulty increased; as reflected in the various workload scores. Stressors, at the levels subjects were exposed to in this study, had no significant effect on secondary task performance. Percent targets hit correlated negatively and significantly with reaction time, whether the stressor was noise or acceleration. In other words, as the percent targets hit increased, reaction times decreased; as reaction times increased, the percent targets hit decreased.

In this research, subjects were instructed to treat the secondary task as a subsidiary task (Knowles, 1963; O'Donnell & Eggemeier, 1986), or one in which the subject avoided degraded primary task performance at the expense of the secondary task. In this paradigm, the RHAW was not used to load the primary task, but rather to determine how much

additional work could be undertaken while the primary tracking task was being performed. The assumption of this paradigm is that the subject will shift some of this reserve processing resources from the low to moderate levels of operator load to higher levels of workload, thus exceeding his capability to compensate, resulting in performance decrements (O'Donnell & Eggemeier, 1986).

Primary tracking task error scores, by themselves, did not reflect the increased workload imposed by the secondary task in this research. Use of the secondary task measure, percent targets hit, permitted a more sensitive analysis of the capacity expenditure than that afforded by the primary task. One can see from the plots of percent targets hit versus task difficulty (Figures 25a, 25b) that as secondary task difficulty increased by the addition of two more targets to process, the percent targets hit decreased. Although only a maximum of four targets were used in this research, one can see that if this number were increased and primary task performance was maintained, percent targets hit would continue to decrease until some level of degraded performance on the RHAW task was determined (such as 50%).

In summary, the percent targets hit subsidiary task permitted a more sensitive analysis of the capacity expenditure of the subjects than that afforded by the primary task, alone.

Secondary Task Reaction Time

Choice reaction time was another secondary task measure employed in this research. Subjects' reaction times to the two or four targets either with or without a primary tracking task were recorded and analyzed. Reaction time correlated significantly with the other secondary task

measure, above, percent targets hit. Several interesting observations about choice reaction times are made.

First, reaction times improved (decreased) as noise levels increased from ambient to 90 dB to 100 dB A-weighted. This improvement observed in reaction times is attributed to the alerting cue phenomenon previously discovered by other researchers (e.g. Teichner, 1963).

Secondly, mean reaction times for acceleration exposures were even lower than those for noise exposures; this improvement may be attributed to training effects since acceleration exposures followed noise exposures, however, acceleration can also be considered an alerting cue and subjects may have tried harder under acceleration.

Choice reaction time tasks can be generally assumed to impose greater central-processing and response selection demands than simple reaction time tasks, or those which employ one discrete stimulus and one response (O'Donnell & Eggemeier, 1986). Investigators have found the P300 latency to be significantly and positively correlated with reaction time (Donchin, Kutas, McCarthy, 1976; Gomer, Spicuzza & O'Donnell, 1976). P300 latency correlated positively (+.649) and significantly (P=.0035) with reaction time during acceleration exposures in this research; P300 latency correlated negatively (-.116) and not significantly (P=.6477) with reaction time during noise exposures. Averaged together, the three noise conditions resulted in a negative correlation for reaction time and acceleration. The ambient noise condition did not result in an increase in P300 latency as the items in memory were increased from 2 to 4 (Figure 31c), however, the 90 and 100 dB A-weighted noise exposures did result in increases in P300 latency and RT as a

function of increasing items in memory. The same effect was observed during the acceleration exposures; baseline acceleration exposures had no effect on P300 latency as the items in memory were increased from 2 to 4 (Figure 31d). A lawful relationship, similar to that observed by previous researchers (Donchin et al., 1976; Gomer et al., 1976), between reaction time and P300 latency was observed for both 90 and 100 dB noise (Figure 31c) and 2.75 Gz and 3.75 Gz acceleration (Figure 31d) exposures.

Man-Machine Response Times (MMRT)

MMRTs were also grouped according to the plant dynamics. The 1/S or velocity plant was much simpler and quicker to drive compared to the $1/S^2$ or acceleration plant dynamics. MMRTs did not correlate significantly with any performance or physiologically-based variables averaged across all subjects and stressors except for tracking error score. As an indicator of continuous reaction time, MMRT was virtually unaffected by stressors, and appears to be only marginally effective as an indicator of mental workload. MMRT did not correlate significantly with secondary task reaction time for either noise exposures (correlation = .231, P=.4705) or acceleration exposures (correlation = .329, P=.2969). In that respect, the MMRT was not a good index of secondary task performance during this study.

Forearm EMG

Although increasing noise stress had no significant effect on subjects' tracking forearm muscle EMG STD, acceleration stress increased EMG STD. Subjects' forearm EMG STDs were significantly higher at the high G level than at the lower or baseline G levels. EMG STD correlated significantly with percent targets hit, reaction time, tracking error

score, P300 latency and amplitude and mean arterial blood pressure during noise stress exposures; and reaction time, tracking error score and P300 latency during acceleration exposures. Never seriously recognized as a physiological measure of mental workload, the standard deviation of the EMG recorded from the brachioradialis muscle (forearm) of the right tracking arm of the subject proved to be the one variable that correlated most significantly with the most variables in this study. The only variable EMG STD did not correlate with significantly was total eye blinks (P=.5244). Laville & Wisner (1965) reported that the EMG of neck muscles correlated with subjective stress in a demanding, precise task better than heart rate correlated with stress. Stackhouse (1976) found EMG signals from the forehead and forearm to be correlated with workload. Grip pressure on a control stick has also been found to increase in high workload tracking tasks (Hikok, 1973; Smith, 1972). Grip pressure, however, can also increase as a function of the operator's effective gain.

In assessing mental workload, the relatively static tension level of a muscle not directly involved in task performance is usually monitored (O'Donnell & Eggemeier, 1986). Some operators may tense their foreheads, neck muscles or other muscle groups while under increased workload. A general muscle tension factor appears to exist for muscles in the upper body which means that muscles of the head, neck, shoulder and forearm should all be sensitive to activation resulting from various types of mental work (O'Donnell & Eggemeier, 1986).

The results of this research indicate that if one monitors the EMG of the principal muscle involved with the visual-motor task being

performed, the mean standard deviation of that signal during the performance period (in this study, 60 seconds) may provide valuable information about both the physical work and mental work the operator is performing. One possible reason why EMG STD correlated so significantly with the variables of workload in this study is that when the STD was large, the muscle was being used more actively. When the forearm muscle was active, the subject was either tracking the difficult-to-control $1/S^2$ plant or was performing the dual task, which required a thumb action as well as hand movement for tracking. It was during these 1/S combinations and dual tasks that the subjects' workload variables increased. Logically, if the increases in EMG STD tracked increases in the other variables as a function of task difficulty, EMG STD should have correlated with many of the variables. The EMG was measuring physical activity and not mental load in its application here, but it was more than a coincidence that this measure of physical activity correlated so well with the other "mental" workload measures. The significant finding, however, was not that the EMG STD correlated with so many of the workload variables but that it did so at significant levels (P=.05).

During those combinations where minor stick deflection was required, such as the 1/S plant combinations or the secondary task-alone combinations, there was not as much forearm muscle activity. These were the combinations that were judged to be less demanding in terms of subjective workload and both the performance and physiologically-based variables were in agreement. As a result, the EMG STDs were smaller for these combinations and accurately tracked these other variables as a

function of task difficulty. This finding warrants further investigation and could be investigated by monitoring pilots, factory workers on assembly lines, secretaries, computer terminal operators, to name a few. Those operators, such as Flight Controllers, who perform no overt manual task with their duties would not be candidates for such an investigation.

Mean Arterial Blood Pressure (MAP)

Mean arterial blood pressures were recorded during the noise exposures, only. MAP tended to increase as a function of task difficulty and/or noise stress. MAP correlated significantly with heart rate, EMG STD and blink duration. Heart rate covaried with MAP during this study; in general, when the performance task caused increased mental workload the heart rate increased and blood pressure (MAP) increased. It is assumed that the stress caused an increase in the release of adrenalin which, in turn, increased the heart rate and blood pressure.

Temporal Artery Flow Velocity & Arterial Oxygen Saturation

The percent Doppler temporal artery flow velocity and arterial oxygen saturation (SaO_2) were two additional physiological variables recorded during acceleration exposures. The Doppler signal provided a means for obtaining an objective measure of acceleration stress on the subject (Table 17). When the blood flow velocity in the temporal artery decreased, as monitored by the Doppler device, mean eye level blood pressure was reduced and the centrifuge subject lost peripheral vision or, sometimes, central vision. The utility of the Doppler temporal artery blood flow velocity monitoring device in acceleration research

has been demonstrated previously (Crosbie, 1984; Krutz, 1973; Rossitano, 1973, 1974).

Relationships Among the Workload Measures

There were some common ties among the workload measures observed during this research. One can review the Spearman Correlation Coefficients and associated P-values and select those measures which were significantly correlated with each other.

Increases in SWAT scores, primary tracking error scores, heart rate, total eye blinks, P300 latency and amplitude and EMG STD were observed as acceleration stress increased from baseline to 2.75 G_z to 3.75 G_z. Eye blink durations and percent targets hit on the secondary task decreased with increasing acceleration. In terms of the workload measures tracking with one another, during acceleration exposures, when workload was high (as indicated by SWAT scores, for example), tracking error scores, heart rate, total eye blinks, P300 latency and amplitude and the EMG STD were all high. Eye blink duration decreased as did percent hits on the secondary task during acceleration exposures.

When workload was increased under noise exposures, P300 amplitude and latency slightly decreased, as did secondary task reaction time, man-machine response time and eye blink duration. Mean arterial blood pressure and EMG STD were slightly elevated under high noise stress.

Although some of these measures' increases and decreases were not statistically significant, they did represent trends in the results and are depicted graphically in Figures 9a-21. The two stressors imposed different levels of workload on the subjects although some of the measures followed the same trend, whether the stressor was acceleration

or noise.

SWAT, eye blink duration and the EMG STD all followed the same trend as a function of increasing stressor. SWAT and EMG STD increased as the stressor level was increased and blink durations decreased. Opposite trend effects were observed in P300 amplitude and latency; P300 amplitudes and latencies decreased as a function of increasing noise stress but increased as a function of increasing acceleraiton. Because these changes were not statistically significant, further investigation of this phenomenon is warranted before offering an explanation. None of the measures demonstrated opposite effects under one stressor as compared to the other stressor.

In summary, there were logical ties observed among the workload measures. When the workload increased, as indicated by increasing task difficulty, tracking error scores increased, percent targets hit on the secondary task fell, reaction times to the secondary task increased and man-machine response times increased. Physiological measures tracked as well; as the task difficulty was increased, heart rates increased, total eye blinks decreased, eye blink durations decreased and EMG STD increased. P300 latencies and amplitudes increased, especially for the addition of two or four targets to the $1/S^2$ acceleration plant tasks. These trends are depicted graphically in Figures 23a-35.

In reviewing these 95% confidence intervals, one notices that the measures tracked well with each other, whether the stressor was noise or acceleration. Two exceptions were P300 amplitude and eye blink duration exposures under noise exposures. The reason why these were different is probably due to recording and analyzing techniques and to the effects of

acceleration on vision rather than due to any unique characteristic of the measure (such as insensitivity in the acceleraiton environment).

Selecting the Best Workload Measures

The principal objective of this research was to assess the effect of noise and acceleration stress on human operator workload and performance. Of interest was to find which measure or measures worked best in the stressor environment; any follow-on or future workload research in noise, acceleration, vibration heat, cold or other environments would be able to capitalize on the results from this work.

One conclusion of this research is that none of the thirteen workload measures investigated, alone, completely depicted the workload imposed by the stressor by the increasing task difficulty. Primary tracking task error scores were virtually unaffected by increasing stressor, but the secondary task measures (percent targets hit and reaction time) reflected significant changes as the workload increased. When evaluated together, these behavior or performance-based measures can provide insight about the effect of the stressor or task difficulty on the subject's workload.

Likewise, the array of physiological variables, when analyzed together, provided a more detailed description of the imposed workload than any one single physiological measure. Eye-related factors demonstrated general workload effects; total eye blinks decreased for the dual tasks and increased for the simple, secondary task-only combinations. Blink durations, evaluated along side total eye blinks, provided no more specific insight, however, into the total eye blink data. P300 latency and amplitude as well as EMG STD data provided more de-

tailed information about the different levels of workload imposed by the different tasks. One can see that as the secondary task was added to the $1/S^2$ or acceleration plant task, P300 amplitudes and latencies as well as the EMG STD increased (Figures 31a,b; 32 a,b; 33a,b). In this research, the P300 measures and EMG STD were sensitive to changes in the performance tasks and demonstrated potential utility as more specific physiological measures of workload than heart rate and eye related factors, for example. Although heart rate increased as a function of increasing task difficulty, one could not distinguish differences in workload between tasks within a plant ($1/S$ or $1/S^2$) by inspecting heart rate data. The P300 latency and amplitude and EMG STD were the physiological measures observed within the framework of this research which offered promise as workload measures which were sensitive to changes in task difficulty.

Mean SWAT scores, the subjective workload measure, changed with each level of stressor and with each level of task difficulty. According to this subjective measure, increasing noise or acceleraiton stress increased mental workload. Other measures, such as primary tracking task error score, man-machine response times, heart rate, eye blinks and blink duration did not always reflect the same changes in workload as did SWAT. SWAT was sensitive to increasing task difficulty within a plant condition like the P300 and EMG STD, and reflected increased workload with higher SWAT scores.

In summary, there is no one single measure that captures the entire essence of workload associated with a performance task. The multidimensional nature of workload demands that multiple measures be used to

cover the entire construct (Wilson and O'Donnell, 1988). The results of this research confirm the multiple measures approach to workload assessment. SWAT was able to distinguish differences in workload associated with the stressor levels and performance tasks in this research. Primary tracking task error scores, in themselves, offered no specific insight into differences between the tasks; however, when evaluated in conjunction with secondary task measures (percent targets hit and reaction time), primary and secondary task measures together provided a more detailed explanation of the workload. Likewise, several of the physiological measures including heart rate, total eye blinks and eye blink duration could not, in themselves, describe the subtle differences in workload imposed by the stressors or performance tasks. However, when these measures were evaluated in conjunction with P300 latency and amplitude data and EMG STD results, a more detailed explanation of the effect of stressor or task difficulty or stressor on workload could be developed.

VII. CONCLUSIONS AND RECOMMENDATIONS

The objective of this research was to assess the effect of high intensity noise stress or sustained acceleration on human operator workload and performance. Noise stress significantly increased subjective mental workload (SWAT scores) as well as mean arterial blood pressures and reduced subjects' reaction times to targets, but had no significant effect on primary tracking error scores, percent hits on the secondary task, or any of the other physiological measures.

Acceleration stress significantly increased SWAT scores, primary tracking error scores, heart rate and total eye blinks as well as the standard deviation of the tracking forearm EMG. The biodynamic stressors' effects on subjective mental workload were reflected in the SWAT ratings. Although the mental effort and time load components of the SWAT increased both as a function of increasing stressor and task difficulty, it was the psychological stress component of the three-dimensional measure that increased the most. Subjects tended to reflect the effect of increasing stressor levels on their subjective mental load in the psychological stress component; increasing task difficulty, on the other hand, was reflected in the mental effort SWAT component.

No single metric completely captured the essence of workload associated with the performance tasks in this research. SWAT scores distinguished differences in workload between tasks, but gave an

inflated effect of noise or acceleration on workload, compared to the other measures. Primary tracking error scores, in and of themselves, provided little insight into the workload imposed by the stressors or task difficulty. However, when this performance measure was coupled with secondary task measures (percent targets hit and reaction time), more insight into the impact of the dual task on workload was afforded. Physiological workload measures, when evaluated as an ensemble, also provided more insight into the imposed workload than that provided by one measure; P300 latencies and amplitudes as well as the tracking forearm EMG standard deviation were sensitive to the changes in task difficulty and reflected significant increases as a function of increasing difficulty.

P300 latencies and amplitudes were unaffected by increased noise or acceleration levels. P300 latencies and amplitudes increased as a function of task difficulty, especially when subjects performed the dual task. P300 latency increases paralleled secondary task reaction time increases for subjects responding to two and four targets, which supports the theory that P300 latency is a reliable indicator of the amount of time a subject takes in evaluating a stimulus.

Heart rates increased as a function of increasing acceleration stress but were unaffected by noise stress. Increasing task difficulty caused subjects' heart rates to increase. Heart rates did not change significantly between tasks in this research, and as a result, the heart rate measure for workload was not sensitive enough to distinguish differences in workload between the tasks.

As indices of mental workload, total eye blinks and blink duration

were only marginally effective in describing the workload imposed by the stressor or by increasing task difficulty. Because of the physiological effects of high G on vision, use of these indices for evaluating mental workload under sustained acceleration may be less effective as it may be difficult to separate the effects of acceleration on vision from the effects of cognitive load on vision. The results of this research reinforce the concept that because of the multi-dimensional nature of workload, multiple resources must be used to cover the entire construct.

Biodynamic stressors such as noise and acceleration can increase operator workload. Other factors including heat, cold, vibration and fatigue must also increase workload. Future studies would include evaluating the effect of these other stressors (heat, cold, vibration, etc) on workload. The effect of combinations of these stressors on workload would also be of interest. Higher stressor or task demand levels should also be investigated. By tracking the workload measures in a stressor environment that resulted in a performance breakdown or in a performance task that imposed too much workload for subjects to perform, one could develop a better understanding about the utility of subjective, performance and physiological measures in predicting workload. Workload measures could be tracked from baseline to redline (danger) regions of stressor or in which the subject is being evaluated. Changes in the workload measures across the entire spectrum (baseline to redline) could then be evaluated and compared with one another in order to develop an array of measures which were sensitive to the performance breakdown. Such research would lead to a better understanding of how subjective, performance and physiological methodologies characterize and, perhaps, predict mental workload in human operators.

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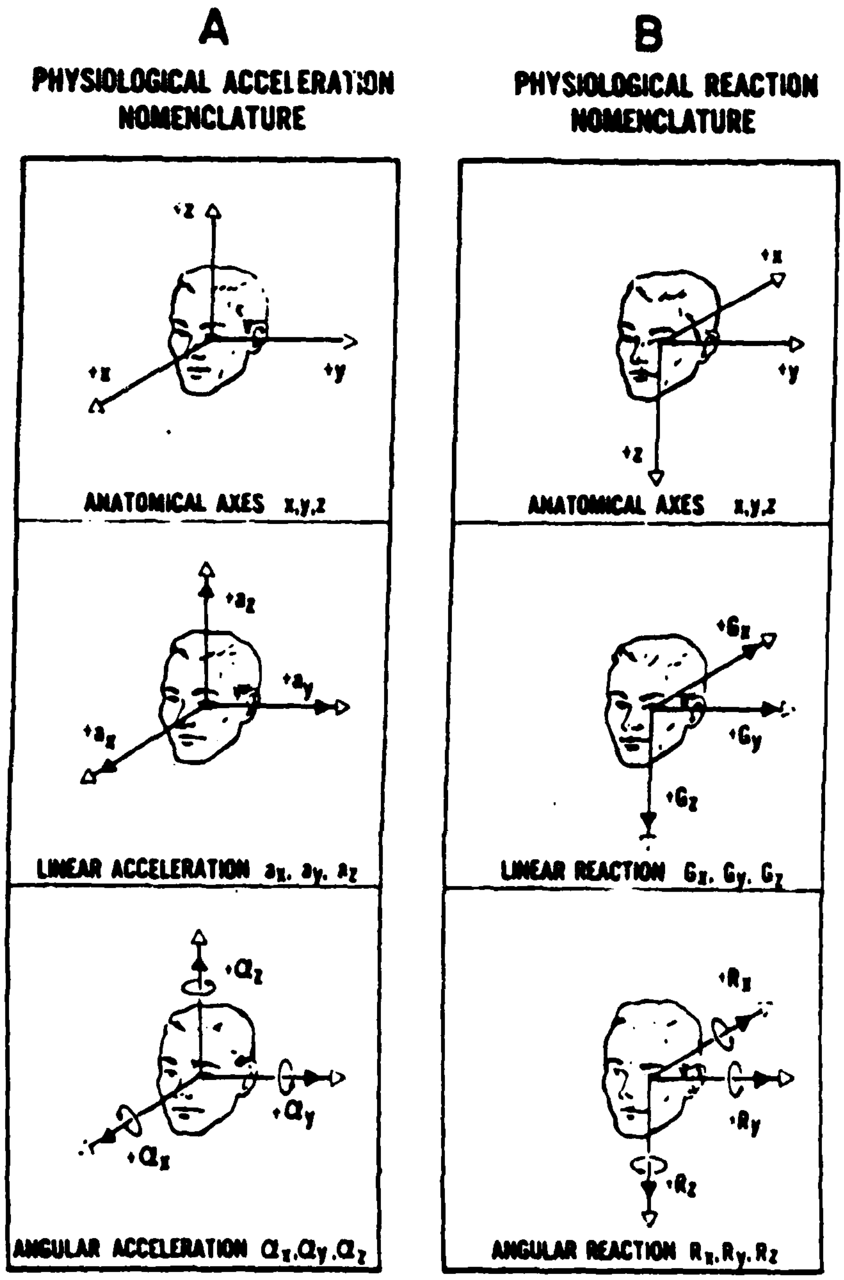
APPENDIX A

Body Axes Accelerations: *Summary*

There is no commonly accepted coordinate system used by physicists, engineers, acceleration physiologists and vestibular physiologists for describing accelerations and inertial reactions in man. Nomenclature for inertial forces acting in humans has somewhat more commonality than does the acceleration nomenclature. The positive directions of the axes used for describing G forces are illustrated in Figure A1B. The relation of these axes follows a backward, inverted right-hand rule. Another useful set of terms for describing reactive forces comprises the "eye-balls" nomenclature: in this system, the direction of the inertial reaction of the eyeballs when the head is subjected to an acceleration is used to describe the direction of the inertial force. Table A1 summarizes the majority of terms used in describing directions of linear accelerations and gravitoinertial forces acting on man and relates these accelerations (Gillingham, 1974).

Table A1. Equivalent Terms for Directions of Linear Accelerations and Gravitoinertial Forces (from Gillingham, 1974)

Acceleration Motions	Gravitoinertial Force	Related Aircraft
+az Headward	+Gz Footward Positive Eyeballs-down	Level Flight Coordinated Turn Pull-up from Dive "Inside" maneuvers
-az Footward	-Gz Headward Negative	Inverted Flight Push-over into Dive "Outside" maneuvers
+ax velocity Forward	+Gx Backward Positive Transverse Chest-to-Back Supine Eyeballs-in	Increasing forward (e.g., application of afterburner) Steep Climb
-ax velocity Backward	-Gx Forward Negative Transverse Back-to-Chest Prone Eyeballs-out	Decreasing forward (e.g., application of speed brakes) Steep Dive
-ay To Right	+Gy To Left Left Lateral Eyeballs-Left	Left Slip Left Skid
+ay To Left	-Gy To Right Right Lateral Eyeballs-Right	Right Slip Right Skid



Figures A1A (left) and A1B (right). System for describing accelerations and inertial reactions in man

Appendix B

Derivation of Reaction Time Measures (Reference Repperger et al., 1979)

It is desired to develop a measure of equivalent reaction time based on a tracking task of a continuous nature. The tracking task consists of a display of the compensatory error (the difference between a target task and the output of the system being controlled). This differs from a pursuit display error consisting of the target and the system output being displayed separately. The subject manipulates a stick controller in the pitch axis. The data required at each time sample (1/25 of a second) are the compensatory error signal $e(t)$ and the error rate $\dot{e}(t)$. A phase plane plot of $e(t)$ versus $\dot{e}(t)$ would appear as in Figure B-1.

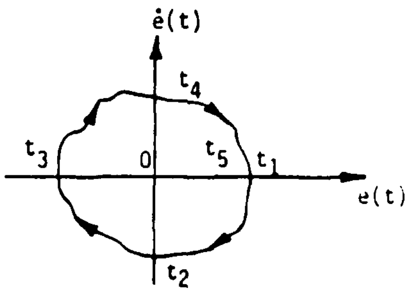


Figure B 1. A Phase Plane Plot of $e(t)$ versus $\dot{e}(t)$

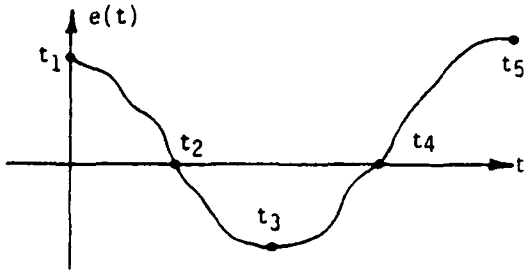


Figure B 2. The Time History Plot of $e(t)$ versus t

At time t_1 the error $e(t_1)$ is positive and $\dot{e}(t_1)$ becomes negative. This continues until time t_2 when $e(t_2) = 0$ and $\dot{e}(t_2)$ is a large negative value. At time t_3, $e(t_3)$ is a large negative value with $\dot{e}(t_3)$ approximate = 0. As time progresses to t_4, $e(t_4) = 0$ but $\dot{e}(t_4)$ is a large positive value. At $t = t_5$, $e(t_5)$ is again a large positive value with $\dot{e}(t_5)$ again going through zero. The cycle is then repeated.

To relate this tracking task to an equivalent reaction time, the classical measure of reaction time is the time it takes to make an error signal go from an initial value to zero. With reference to Figures B-1 and B-2, this would be 1/4 of the cycle time. Let T = the total time for the compensatory error signal to complete one circle in the phase plane. Then

$$T = \sum (t_2 - t_1) + (t_3 - t_2) + (t_4 - t_3) + (t_5 - t_4)$$

or $T = t_5 - t_1$

Then an equivalent reaction time could be defined for this problem as:

$$T_{eq} = 1/4T = 1/4[t_5 - t_1]$$

The equivalent reaction time will be used as a dependent variable to assess the difficulty of the five forcing functions and three plants used. The ANOVA tests can be made with respect to Table B-1.

Forcing Functions		f_1	f_2	f_3	f_4	f_5
	P_1	τ_{11}	τ_{12}	τ_{13}	τ_{14}	τ_{15}
Plants	P_2	τ_{21}	τ_{22}	τ_{23}	τ_{24}	τ_{25}
	P_3	τ_{31}	τ_{32}	τ_{33}	τ_{34}	τ_{35}

Table B 1. Table of Equivalent τ Values for Plants and Forcing Functions

To test for difficulty of the forcing functions, a comparison is made across the fi values for a fixed plant. This answers the question "Does τ_{eq} change as fi increased?" To answer the question of τ_{eq} changing as a function of plant for a fixed fi, an analysis is conducted down a column (across plants and for a fixed fi value).

The traditional speed accuracy analyses that occur can be handled with Figures B-1 and B-2. A highly accurate response occurs when the amplitude of e(t) in Figure B-2 is small. In Figure B-1 this is equivalent to a circle of very small diameter. In general, τ_{eq} will be much longer for this accurate tracking. For the cases of less accurate tracking, the amplitude of e(t) in Figure B-2 would be larger and the diameter of the circle of Figure B-1 would be larger. This would occur for smaller values of τ_{eq}. Figure B-3 illustrates a speed accuracy trade-off using this phase plane analysis:

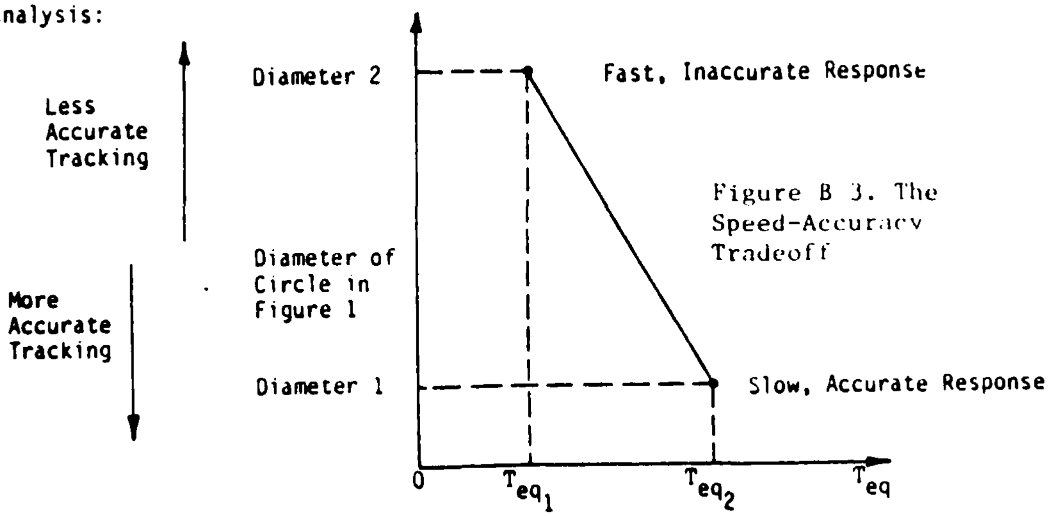
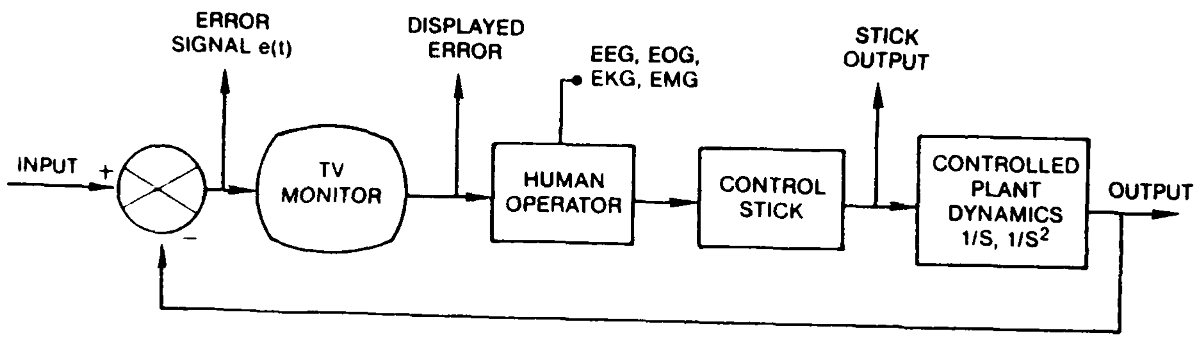


Figure B 3. The Speed-Accuracy Tradeoff

The closed-loop control system that the subjects use in tracking is shown in Figure B 4 In the research described herein, subjects tracked with either a velocity (1/S) or acceleration ($1/S^2$) plant.

FIGURE B 4

MAN-MACHINE CONTROL SYSTEM BLOCK DIAGRAM



MAN-MACHINE RESPONSE TIME — MMRT

APPENDIX C

Data Recording and Analysis on the NWTB

Four of the physiological signals analyzed in this research were recorded on the Neurological Workload Test Battery or NWTB (Figure C). The NWTB is an electronic strip chart recorder and computer-based analysis tool developed for the Workload and Ergonomics Branch of the Human Engineering Division of the Armstrong Aerospace Medical Research Laboratory. The NWTB takes amplified physiological signals and records these signals in 10 second blocks of digitized information. A series of 10 second blocks can be recorded in order to capture a 60 second exposure, for example. In this research, 5-ten second blocks were recorded for each 60 second exposure; the last ten seconds were not recorded or analyzed. The secondary task was not presented during the last five seconds of each dual task trial in order to preclude the possibility of the subject not responding in time to the target before the task ended. After calibrating the NWTB to the amplifiers used in the study, the NWTB was placed in the RECORD mode for each subject's data collection. Several trial exposures were recorded and analyzed prior to actual data collection in order to assure the data were being recorded properly and that all of the electrodes were placed correctly. Data collection began concurrently with the onset of the tracking problem. The NWTB operator observed the closed-circuit TV monitor at the NWTB station; each trial was preceded by a 15 second countdown to

the start of the next trial. Subject data were recorded as files and numbered according to the combination attempted. The file name included the subject's initials and the combination. During data analysis, each file could then be recalled and either heart (H), eye (E), EMG (M) or visual evoked response (A - for audio rare event analysis) preceded the subject's initials and the combination number.

Analysis

Analysis of the data recorded on the NWTB was a time-consuming task. On the average, a 24 trial subject run required over 12K bytes of storage on each Winchester disk. Because of the high cost of 10M byte Winchester disks ($85 ea), ten were purchased for the study and their contents were transferred to digital magnetic tape during heavy subject data recording periods. Four physiological variables were analyzed including heart rate, eye blink, muscle electromyogram and the visual evoked response. The analysis technique for each of these variables is described below. All were recorded in five contiguous blocks for each combination.

Heart Rate

The heart rate analysis routine allows the NWTB user the flexibility of selecting several parameters prior to the actual analysis of the EKG record. Amplitude of the R wave, R to R interval maximum and minimum times allowable and R wave slope conditions can all be preselected. During the analysis of these data, the standard default conditions were employed for most trials (Figure C1).

After selecting the analysis parameters, the first one second of the first 10 second block could be displayed on the screen. After drawing the tracing, the analysis program placed an asterisk next to the

waveform it selected as the R wave (Figure C2). If this selection appeared correct, the researcher could then have the NWTB analyze the EKG data for the entire trial by entering a "C" for compute. This took an average 30 seconds each trial. After the analysis was complete a record was displayed for that trial's EKG results (Figure C1). If there were no bad beats and the variance in the beats appeared normal, the trial could be accepted and the inter-beat interval recorded (Figure C3). A plot of the inter-beat interval was also made available to the researcher, if desired, which gave a pictorial record of the variation in heart rate during the first 50 seconds of each trial (Figure C3).If, however, there were problems with the EKG record, the R-R interval was longer than 1200 msec or there was noise on the recording, the program could not accurately select the R wave and EKG analysis results indicated "bad beats." In many instances, these "bad beats" could be corrected by changing one of the four analysis parameters offered at the beginning of each trial. One problem encountered with the current version of the heart rate analysis routine is that it is unable to correctly identify R waves that fall directly at the end or beginning of a 10 second trial. This occurred several times throughout the analysis of all nine subject's data and had a slight effect on the interbeat interval. What is needed with this analysis software is the ability to allow the researcher to physically move the asterisk to the correct R wave in order to speed up the analysis. Such a capability resides in the eye blink analysis routine described below.

Eye Blink

The eye blink analysis was similar to that for the EKG in that the total number of eye blinks were recorded as well as the interval

between blinks, but other parameters were also provided including closure duration. After the eye blink analysis was complete a record was displayed for the first ten second interval. Because eye blinks were extremely difficult to select, each ten second interval for each of the 48 trials (24 trials x 2 days) for experiment I and 24 trials for experiment II were reviewed. In addition, in order to aid the analysis, video tapes were reviewed for each subject for each trial in order to determine when and if each subject blinked. In some trials, subjects never blinked. In other trials, subjects blinked over 60 times. The eye blink analysis routine selected the onset of a blink and drew a line to the abscissa or time line of the record (Figure C4). If a blink was not selected by the routine, the researcher had the option of changing the original default parameters or selecting the blink with a movable cursor on the keyboard. The latter technique proved to be the most expeditious and was used most of the time. After all blinks for all five 10-second records were selected, composite eye blink results were displayed. This represented eye blink results for one trial (Figure C4).

Right Arm EMG

Electromyogram (EMG) data from the brachioradialis muscle of the right arm of each subject was analyzed for each trial. The EMG analysis routine provides no plot of the record, however, it does give totals for each of the 10 second trials as well as totals. The analysis routine involves a Fast Fourier Transform of the frequency data in order to convert it from the frequency to the time domain. The routine analyzes the power in the EMG signal in 4 different "bands" (Figure C5). Power in the 10, 20, 30 and over 30 bands is computed for the entire 50 seconds and then listed in a table of results (Figure C5). One would

expect a simple, thumb actuating a switch type task to require very little arm muscle activity, whereas a dual tracking and target reaction task to require a great deal of arm muscle activity.

Visual Evoked Response

The most time consuming analysis was the visual evoked response (VER) for each trial for each subject. This routine recorded one second snap-shots of the event related potential (ERP) recorded from the scalp of each subject. This one second record was triggered externally by the appearance of a threat target or a flashing target aircraft, as described in the Methods and Materials section. The audio rare event analysis routine was selected because the task selected in this research was very similar to the "odd-ball" paradigm described by Donchin et al. (1984). Twenty percent of the secondary tasks (targets) presented were threats, similar to the 20% odd tones presented by Donchin et al. (1984). Both the rare and frequent ERPs were recorded on the first four subjects. Rare ERPs were the one second scalp potentials following the appearance of a threat or the flash of the target aircraft. The ERPs resembled the classical transient evoked response (Figure C6) in that positive-going and negative-going traces were observed with the third positive peak usually selected as the P300 or P3.

VER analysis was performed for each trial for subject. There were two modes of analysis offered for each 50 second record of ERPs. The researchers could select the ".DAT" suffix to see an overall analysis of the ERPs, or the ".DST" suffix to observe individually triggered ERPs. Following the selection of default parameters the researcher was presented with the composite ERPs recorded throughout the 50 second period. In several instances, there was a problem with the recording

path or else the subject blinked excessively and all ERP records were lost for that trial. If, however, all ERPs were successfully recorded, a typical composite record appeared as shown in Figure C7. This figure shows the composite ERPs for Day I combinations 23, 9 and 17 from Experiment I for one of the subjects. These combinations were for the 1/S-2 task and were at ambient 40 dB (23), 90 dB (9) and 100 dB (17), respectively. The figures at the right side of each tracing indicate the number of trials the filtered composite is made from. If one looks for a similar positive-going peak among all three ERPs, one is obvious around the middle of the record. If the records for Day 2 are then superimposed over Day 1 results (Figure C8), it is possible to select the P300 peaks and then compute the amplitudes and latencies (Figure C9).

FIGURE C. NEUROLOGICAL WORKLOAD TEST BATTERY

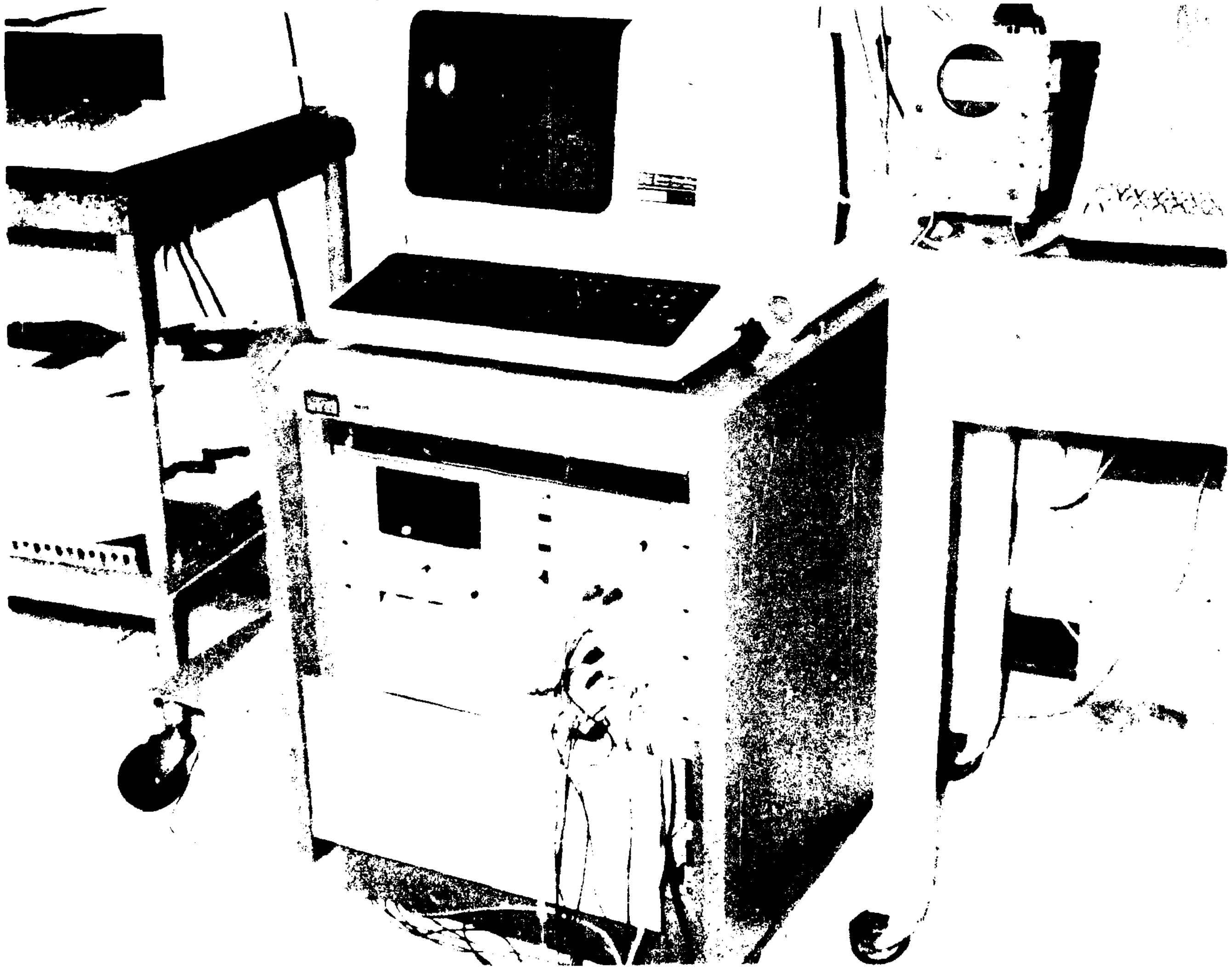


FIGURE C1

HEART RATE ANALYSIS

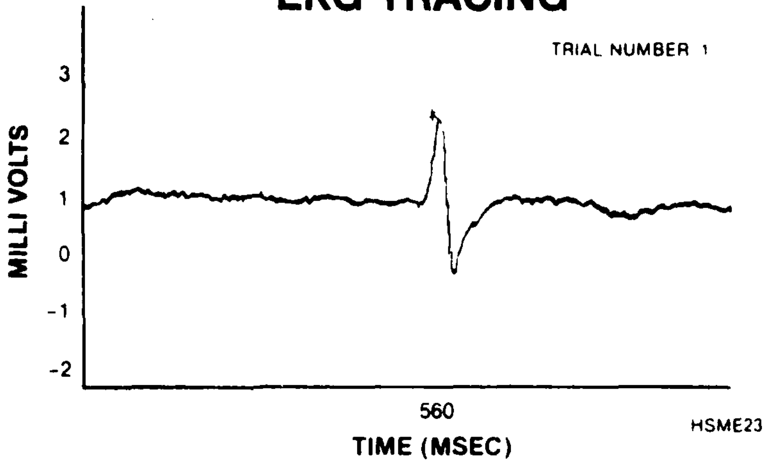
CARDIAC AMPLITUDE: 29
DIFFERENCE CRITERION: 199
MAXIMUM TIME BETWEEN R WAVES: 1000
MINIMUM TIME BETWEEN R WAVES: 400

TRIAL	BEATS	BAD BEATS	MEAN IBI	VAR	STD DEV	MEAN BPM
1	13	0	769.41	1658.63	40.72	77.98
2	13	0	761.41	328.27	18.11	78.80
3	13	1	762.27	1222.44	34.96	78.71
4	13	2	703.90	1080.90	32.87	85.23
5	13	0	785.66	1283.31	35.82	76.36
GRAND STATISTICS			757.34	1793.92	42.35	79.22

HTR106

FIGURE C2

EKG TRACING



NUMBER OF R-WAVES FOUND 1

FIGURE C3

INTER-BEAT INTERVALS

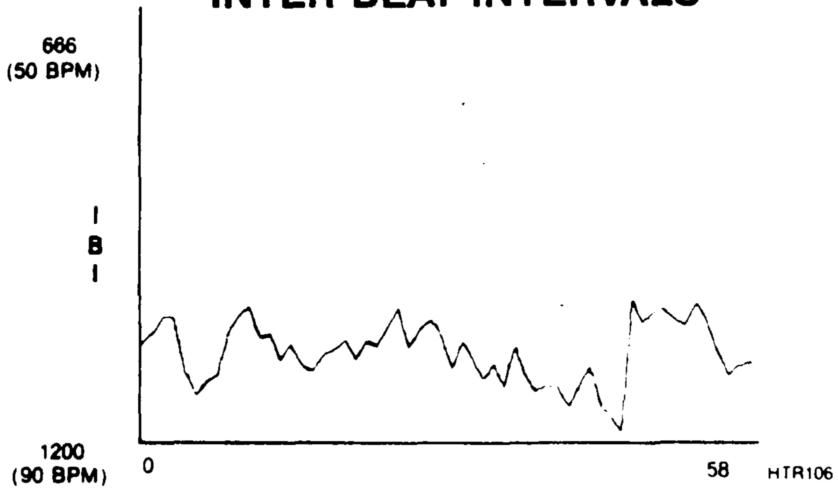
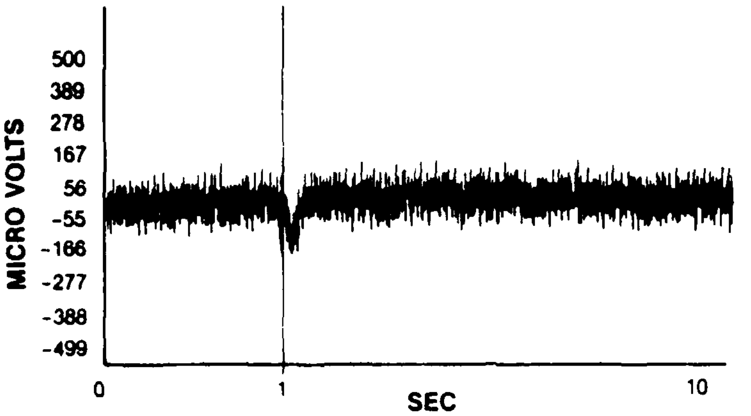


FIGURE C4

EYE BLINK AND BLINK DURATION ANALYSIS

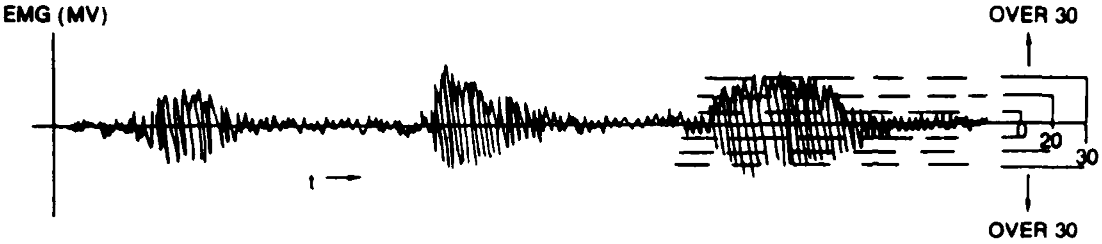


NUMBER:	1
ONSET TIME (MSEC):	2790
AMPLITUDE (MICRO VOLTS):	208
DESCENT TIME (MSEC):	40
CLOSING DURATION (MSEC):	170
50 WIN. DURATION (MSEC):	70

EPKD02

FIGURE C5

EMG ANALYSIS



TIME (SEC)	MEAN	VAR	ST DEV	10	20	30	OVER
10	0.0	150.56	12.27	7074	2198	557	171
20	-0.1	180.56	13.43	6633	2427	625	315
30	0.0	413.03	20.32	4408	2929	1511	1152
40	0.0	208.98	14.45	6077	2720	885	318
50	0.0	237.91	15.42	5693	2718	1048	541
TOTAL	-0.0	238.20	15.43	29885	12992	4626	2497

FIGURE C6

CLASSICAL TRANSIENT EVOKED RESPONSE TRACING

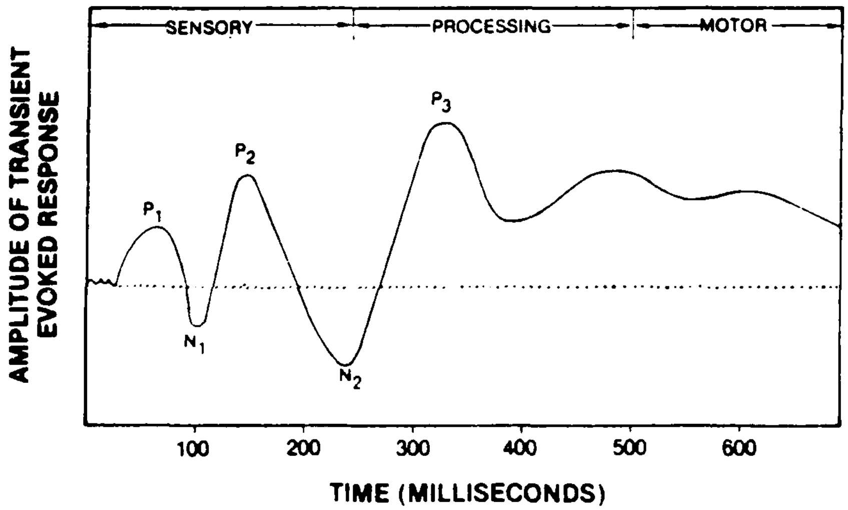


FIGURE C7

P300 ANALYSIS, DAY 1

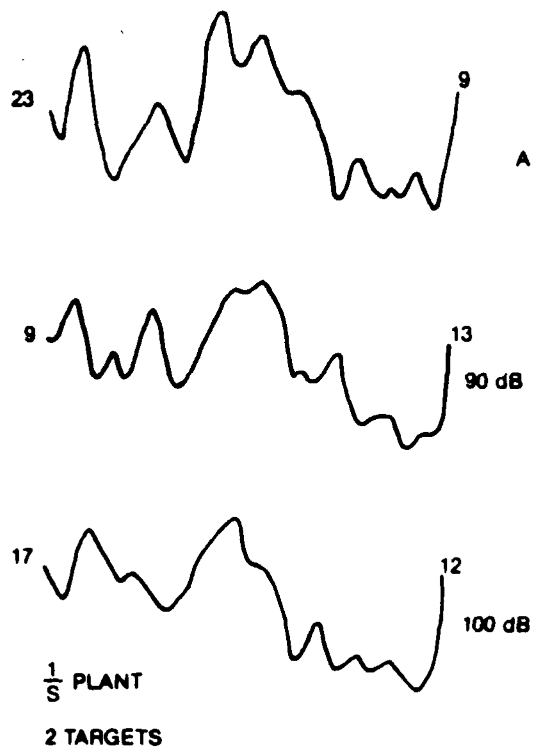


FIGURE C8

P300 ANALYSIS, DAY 2

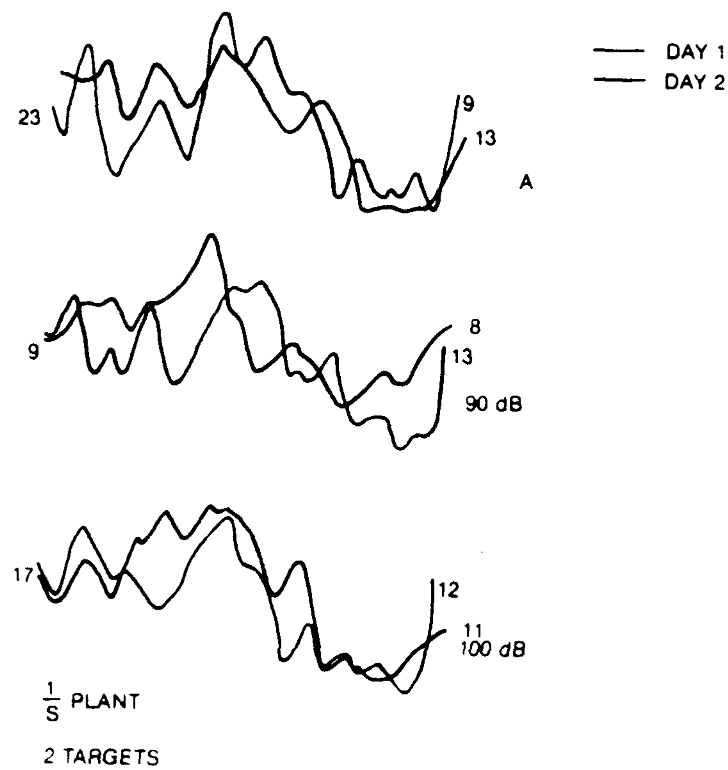
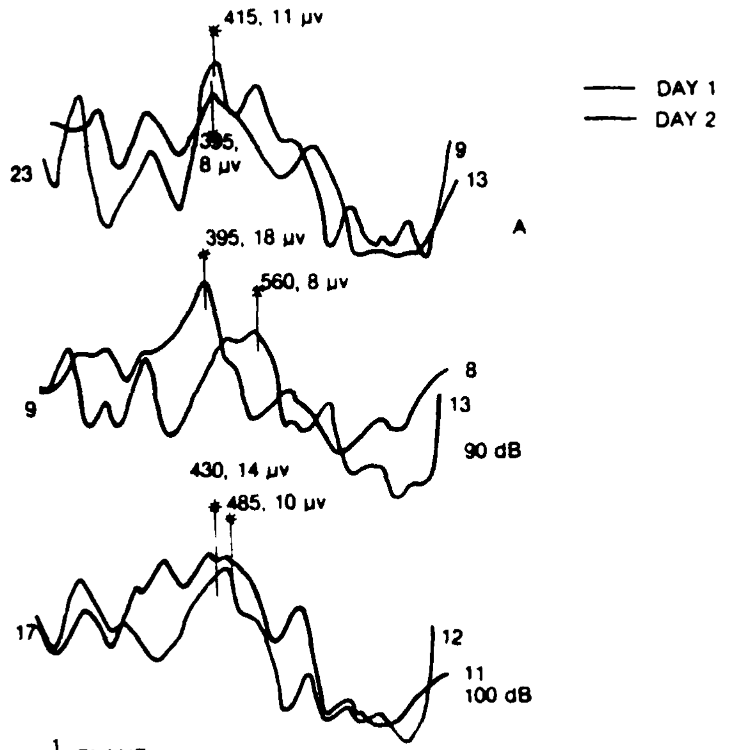


FIGURE C9

P300 ANALYSIS, SELECTIONS



$\frac{1}{S}$ PLANT

2 TARGETS

APPENDIX D

Pilot Study - Selection of Performance Tasks

This initial experiment was conducted in two phases. During phase I, subjects performed the compensatory tracking task, described in Methods and the three plant dynamics (P1, P2, P3) were evaluated with all five forcing functions. The experimental design is shown in Table D1. Phase II involved the evaluation of the dual tasks (primary tracking task plus the secondary, RHAW, task). Subjects were also exposed to noise stress in order for them to become familiar with 90 dB and 100 dB A-weighted noise stress; all subjects were already familiar with acceleration stress.

Phase I - This phase was conducted in the laboratory but with seat and crt geometries as similar as possible to the centrifuge cab seat and crt geometries. Subjects tracked the vertically moving aircraft (Figure D1) using either the P1, P2 or P3 plant dynamics. The aircraft's forcing function or speed was either 1, 2, 3, 4 or 5; 1 was the slowest and 5, the fastest. The five subjects who completed phase I, received one day of familiarization and three days of training. Each training day consisted of fifteen 30 second tracking exposures. All three plant dynamics were used to track the five target speeds for a total of 15 conditions. Referring to Table D1, subject 1 tracked plants in the order P1, P2 and then P3 across all five target speeds on Day 1 and then plants P2, P1 and P3 on Day 2. The order of the 5 forcing functions

were randomized among the plant conditions, however, the subjects were told prior to the task which speed they could expect. There was a fifteen second rest between each exposure. On Day 4, data was collected. All subjects had reached asymptotic performance by day 4 as their day 3 scores were within 5% of their day 2 scores. Mean error scores across all five subjects versus plant dynamics and forcing function (target speed) were computed.

Phase II - This phase was also conducted in the laboratory with methods and materials the same as in Phase I. The same five subjects from phase I tracked with all three plant dynamics, again, but a forcing function of 1 was selected for all three plants based upon the results of Phase I. In addition, subjects were presented with the secondary task which was either 1, 2 or 4 threats (Figure 2) presented randomly among 5 nonthreats. There was also a 0 threat condition during which the subject performed the tracking task, only. The 15 combinations including plant dynamics and the number of threats are shown in Table D2. There was no attempt to counterbalance this design and subjects were trained by starting with combination 1 and ending with combination 15. Noise stress was also introduced during Phase II only to familiarize the subjects with the 90 and 100 dB A-weighted pink noise. Subjects practiced giving SWAT scores after each 60 second combination. After three days training, data was collected on Day 4. A man-machine response time or MMRT was also developed to give a continuous tracking reaction time measure. This MMRT is described in Appendix B. MMRTs as a function of plant dynamics and forcing function were also computed as well as mean error score. Mean SWAT scores, mean error scores and mean percent targets hit for the five subjects as a function of plant

dynamics, number of threat targets and noise stress were computed. After analyzing the results, the eight tasks described in Methods and Materials Methods were selected and carried forward into experiments I and II.

Results

Phase I: Tracking error score means were computed for the subjects and plotted on Figure D2. An ANOVA was performed on the means for all five subjects (Tables D3,4) for score and reaction time (Man-Machine Response Time or MMRT). F-tests (Table D5) showed a significant difference among the plants for score (P=.0001) and for MMRT (P=.0001) and among the forcing functions for score (P=.0002) but not for MMRT (P=.7643).

Phase II: No statistical analysis was performed on the data from this phase. Means of five subjects were recorded and plotted (Figures D7, D8, D9).

Discussion

Phase I: From the plot in Figure D2 it was determined that error scores for both plant P1 (pure gain plant) and plant P2 (1/S or velocity plant) were essentially the same across all target speeds or forcing functions. The error scores for plant P3 ($1/S^2$ or acceleration plant) were significantly higher than those for P1 and P2 and more spread out. The P2 plant used in tracking the aircraft with a forcing function of 1 resulted in the lowest mean error score and the P3 plant used in tracking the aircraft with a forcing function of 4 resulted in the highest mean error score. There was no significant difference found between the tracking scores for the P1 and P2 plants but there was a difference found between P1 and P3 as well as P2 and P3 (Figure D3). Forcing function appeared to have a direct effect on mean error score, that is,

as the forcing function increased, the mean error score increased (Figure D4). Man-machine response time (MMRT), like mean error score, was not significantly different between plants P1 and P2, however, P1 and P3 as well as P2 and P3 MMRTs were significantly different (Figure D5). Forcing function had no real significant effect on MMRT (Figure D6).

It was decided to carry forward into Phase II all three plant conditions with a forcing function of 1. These conditions resulted in a wide range of tracking error scores and were judged reasonable by the subjects in terms of tracking.

Phase II: Means for all five subjects were computed and plotted. Mean error scores for P1 and P2 in combination with threats and noise were not different from one another, however, they appeared to be different from P3 (Figure D7). The plant P3 condition showed that as the number of targets increased, the mean error score increased. No difference in mean percent hits of threat targets was found as a function of plant or trial during the pilot study (Figure D8). Mean percent hits for the threats-alone condition was better than those conditions in which any of the plants, P1, P2 or P3 were in combination with the threats (Figure D8). One can see that as the number of threats increased from 1 to 2 or 4 the mean percent hits dropped consistently (Figure D8). Mean SWAT scores demonstrated some interesting combinations (Figure D9). As the task difficulty and noise increased, the subjective SWAT rating increased, regardless of plant. Plants P1 or P2 SWATs were similar, however, plant P3 SWAT ratings were higher than those for P1 or P2 (Figure D9).

The results from Phase II made it possible to reduce the number of

plant and target conditions to carry forward into experiments I and II. Because plants P1 and P2 were quite similar in terms of mean error score, percent hits, man-machine response time and SWAT ratings, it was decided to drop the P1 condition since it was so similar to P2 in its effect on subject tracking. P2 demonstrated a wider range of SWAT scores (Figure D9) and a wider range of percent hits (Figure D8). Furthermore, the one and two target conditions resulted in similar error scores, percent hits and SWAT scores and it was decided to drop the one target condition. This decision resulted in two target conditions (2, 4) with two plant ($1/S$, $1/S^2$) conditions for experiments I and II. When combined with target only and plant only tasks, these two conditions resulted in the eight tasks selected and discussed in the Description of the Performance Tasks section of Methods and Materials.

FIGURE D1

PRIMARY TASK DISPLAY

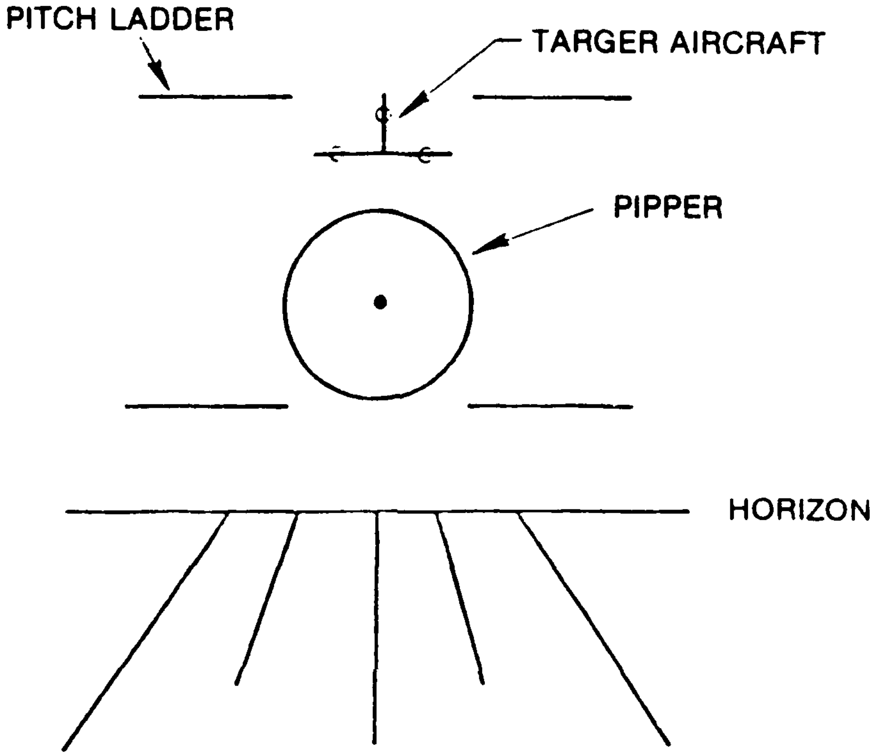


FIGURE D2

TRACKING ERROR SCORE AS A FUNCTION OF FORCING FUNCTION vs PLANT

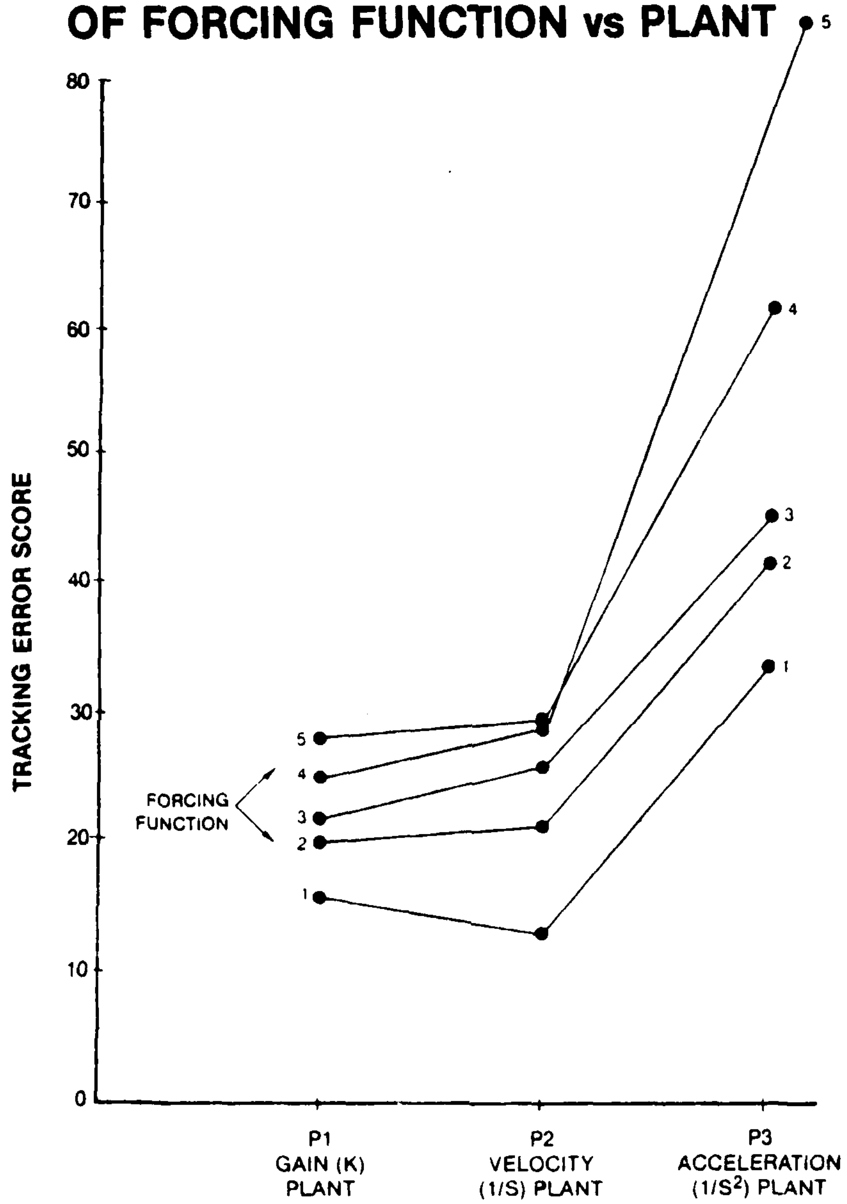


FIGURE D3

95% CONFIDENCE INTERVALS FOR MAN-MACHINE RESPONSE TIME vs PLANT

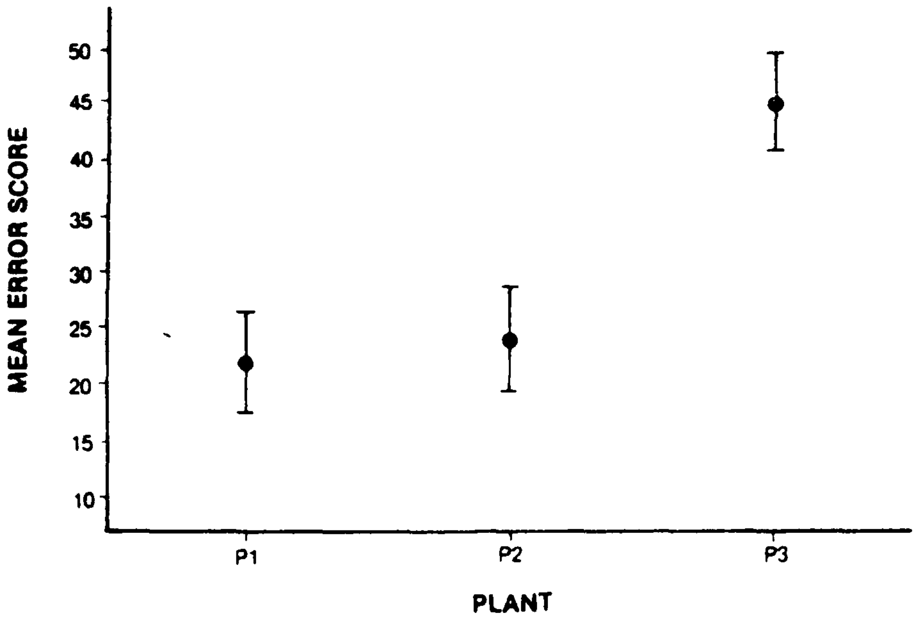


FIGURE D4

95% CONFIDENCE INTERVALS FOR MEAN SCORE ERROR vs FORCING FUNCTION

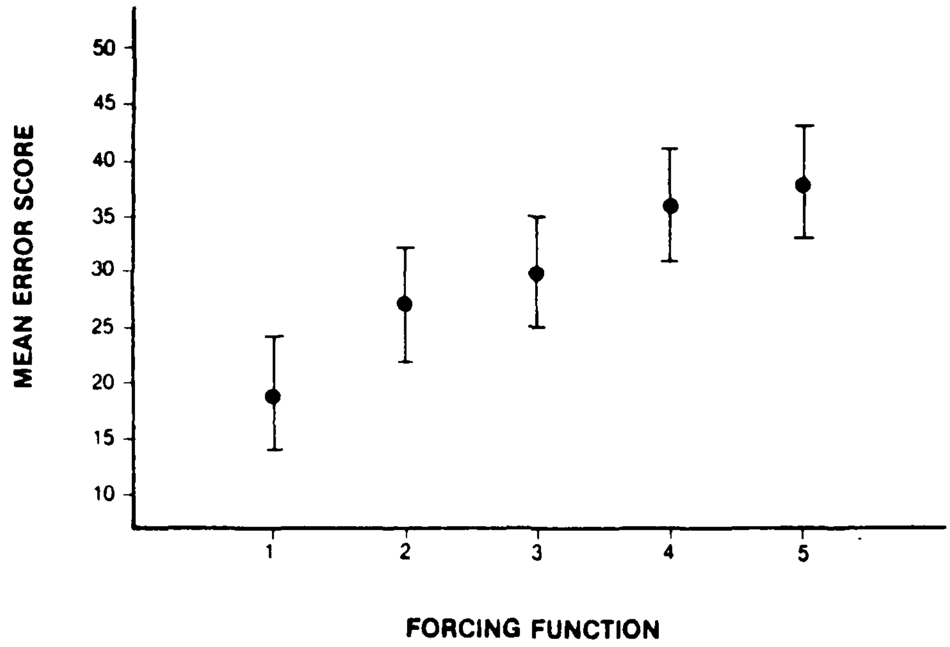


FIGURE D5

MEAN ERROR SCORE vs MAN-MACHINE RESPONSE TIME

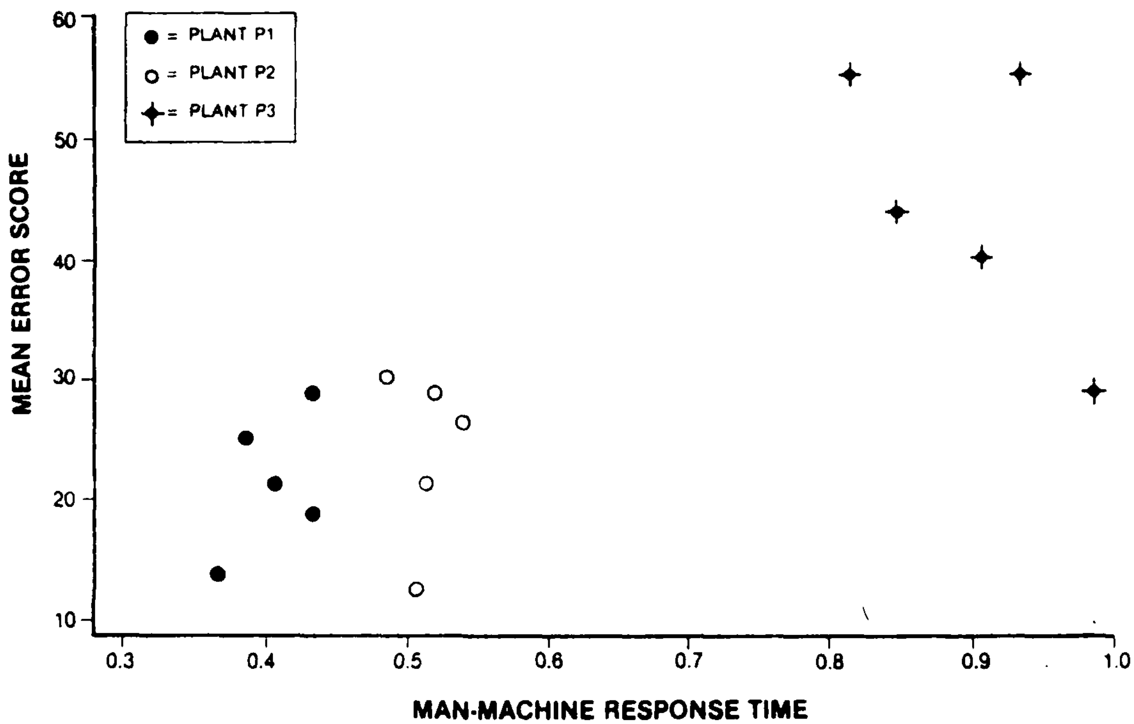


FIGURE D6

95% CONFIDENCE INTERVALS FOR MAN-MACHINE RESPONSE TIME vs FORCING FUNCTION

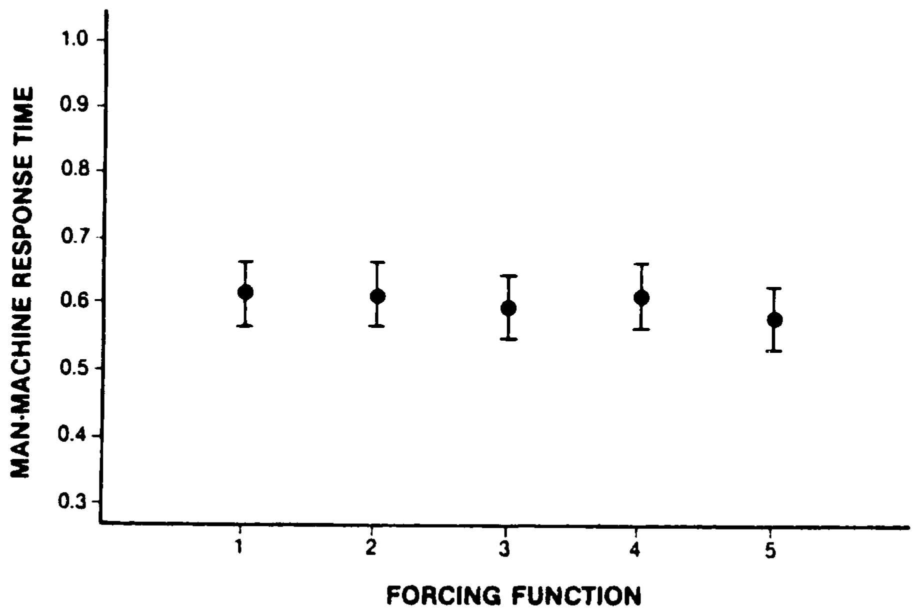


FIGURE D7

MEAN ERROR SCORE FOR ALL PLANT COMBINATIONS—PRIMARY TASK PERFORMANCE

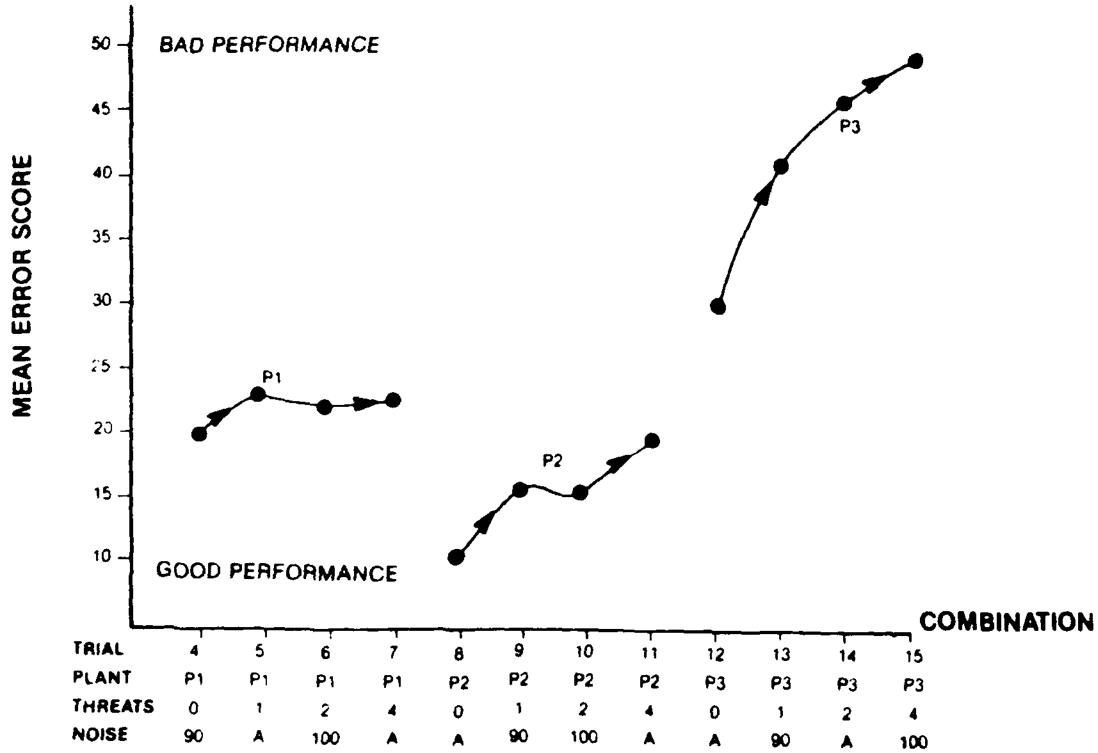


FIGURE D8

SECONDARY TASK (RHAW)
PERFORMANCE FOR EACH COMBINATION

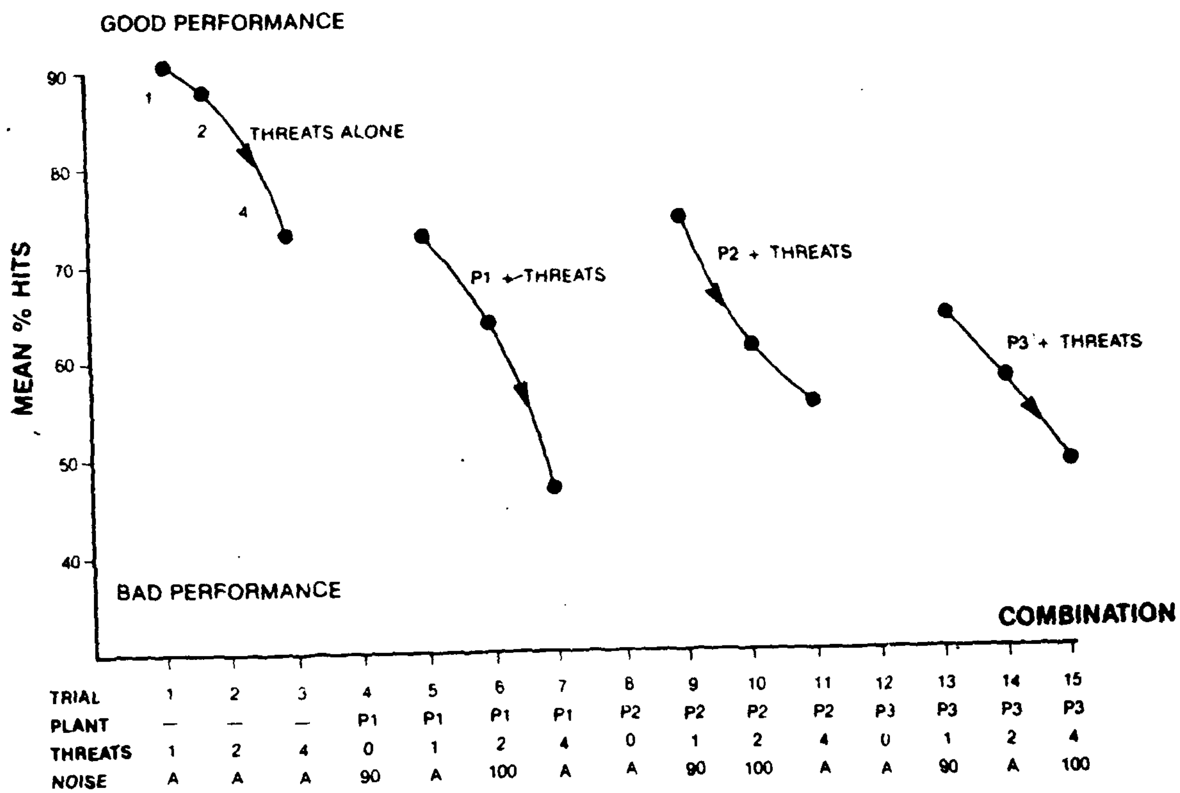


FIGURE D9

MEAN SWAT SCORE FOR EACH COMBINATION

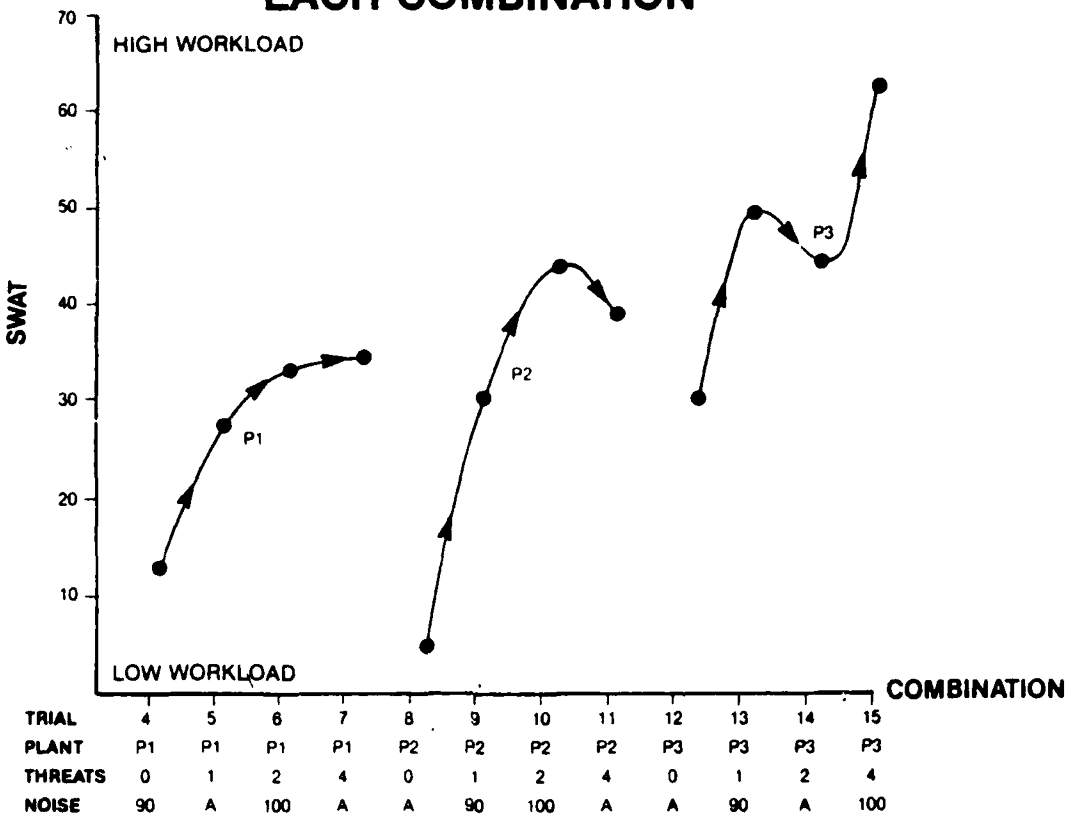


TABLE D1

PLANT/FORCING FUNCTION EXPERIMENTAL DESIGN

	TRAINING			DATA
SUBJECT	DAY 1	DAY 2	DAY 3	DAY 4
1	P_1 P_2 P_3	P_2 P_1 P_3	P_3 P_1 P_2	P_2 P_3 P_1
2	P_2 P_1 P_3	P_3 P_2 P_1	P_1 P_3 P_2	P_1 P_2 P_3
3	P_3 P_1 P_2	P_1 P_3 P_2	P_2 P_1 P_3	P_2 P_3 P_1
4	P_2 P_3 P_1	P_3 P_2 P_1	P_1 P_3 P_2	P_2 P_1 P_3
5	P_1 P_3 P_2	P_2 P_1 P_3	P_3 P_2 P_1	P_1 P_2 P_3

PLANTS: $P_1 = K$
$P_2 = K\,S$
$P_3 = K\,S^2$

TABLE D2

TRAINING AND SELECTION EXPERIMENTAL DESIGN FROM PILOT STUDY

COMBINATION	PLANT	THREATS	NOISE (dB)
1	—	1	A
2	—	2	A
3	—	4	A
4	P1	0	90
5	P1	1	A
6	P1	2	100
7	P1	4	A
8	P2	0	A
9	P2	1	90
10	P2	2	100
11	P2	4	A
12	P3	0	A
13	P3	1	90
14	P3	2	A
15	P3	4	100

P1 = K, FORCING FUNCTION 1
P2 = K/S, FORCING FUNCTION 1
P3 = K/S^2, FORCING FUNCTION 1
A = AMBIENT NOISE

TABLE D3. ANOVA TABLE FOR ERROR SCORE

Source	DF	Sum Of Squares	Error Term	F-Value	P-Value
Subject	4	381	Error	1.48	.2315
Plant	2	7960	Subject*Plant	50.75	.0001
FF	4	3591	Subject*FF	10.71	.0002
Subject*Plant	8	627	Error	1.22	.3199
Subject*FF	16	1342	Error	1.30	.2542
Plant*FF	8	364	Error	0.71	.6633
Error	32	2059			
Total	74	16323			

FF = Forcing Function

TABLE D4. ANOVA TABLE FOR REACTION TIME

Source	DF	Sum of Squares	Error Term	F-Value	P-Value
Subject	4	0.182	Error	5.79	.0013
Plant	2	3.395	Subject*Plant	52.13	.0001
FF	4	0.018	Subject*FF	0.46	.7643
Subject*Plant	8	0.258	Error	4.11	.0018
Subject*FF	16	0.153	Error	1.26	.2622
Plant*FF	8	0.098	Error	1.56	.1756
Error	32	0.251			
Total	74	4.331			

FF = Forcing Function

TABLE D5

MAIN EFFECTS FOR PLANT AND FORCING FUNCTION

PLANT	SCORE (LSD = 5.8)	PLANT	MMRT (LSD = .12)
1	21.8	1	.40
1/S	23.7	1/S	.51
$1/S^2$	44.5	$1/S^2$	.90

FORCING FUNCTION	SCORE (LSD = 7.1)	FORCING FUNCTION	MMRT (LSD = .08)
1	18.6	5	.58
2	26.9	3	.60
3	30.4	4	.61
4	36.3	1	.62
5	37.8	2	.62

NOTE: MEANS CONNECTED BY THE SAME LINE ARE NOT SIGNIFICANTLY ($P < .05$) DIFFERENT

APPENDIX E

The Effect of Noise and Acceleration Stress on Human Performance - Literature Review

The specific effect of noise stress on human performance is almost as elusive as the definition for mental workload. Mixed results exist regarding the effect of high noise stress (100 dB) on operator performance.

Noise and Performance Literature Review

In his review of the literature on the experimental evidence of the effect of noise on human performance, Kryter (1970) concluded that most studies which showed deleterious effects of noise could be criticized on the basis of faulty experimental procedures. Koelega (1986) confirmed this opinion in his evaluative review of noise and vigilance in which he concluded that the literature on the effects of noise on monitoring performance shows a disappointing lack of consistency in results. Apart from the obvious masking effects of noise resulting in performance decrements on tasks that require perception of auditory signals, noise can cause decreases in efficiency on nonauditory - dependent tasks (Beljan, Rosenblatt, Hetherington, Lyman, Flaim, Dale, and Holley, 1972). Jerison (1963) concluded that [illegible] dB noise can cause measurable changes in human performance. Jerison found that time judgment was distorted by noise as was performance on a mental counting task. Ambient white noise (50-90 dB) was found to have no significant effect

upon vigilance performance (Blackwell & Belt, 1971). Broadbent and Gregory (1965) found that 100 dB noise increases performance decrements on vigilance tasks. Hamilton and Copeman (1970) showed that 100 dB noise increased performance on a tracking task. In one study, (Grimaldi, 1958) a tendency for more errors and less precision was observed when working in a noisy environment. Response times were slower and the number of errors greater when noise levels ranged between 90-100 dB and the frequencies were the highest. One of the most prevalent theories explaining the effects of noise on work performance is the distraction-arousal theory (Teichner, 1963). The distraction-arousal theory holds that noise can have two distinct effects on a person. One effect is to distract the subject from what he is doing and the second effect is to increase the subject's level of arousal.

Noise as an environmental stressor can be acute, short-term or chronic. Sonic booms or sudden loud noises can affect performance by distracting the subject. Chronic noise exposure, even where the ambient noise is high such as in a cockpit, tends to show no detrimental effect on performance. This phenomenon may be due to subject adaptation to the noise. Short-term or intermittent noise has been shown to be the most distracting and performance degrading (McCann, 1969; Poulton & Chin, 1970).

Typical noise levels have been recorded in the F-16A aircraft (Hille, 1979). Noise levels as high as 117 dB A-weighted in an F-16A cruising at 5000 feet at 480 knots indicated airspeed with the environmental control system on (defogger on maximum speed) have been recorded in the cockpit. The helmet (HGU 2A/P with custom liner)

suppressed this noise level approximately 20 dB A-weighted but noise levels ranging between 90-120 dB A-weighted are not uncommon in the F-16A cockpit (Hille, 1979).

The effect of noise on primary and subsidiary task performance has been examined (Bell, 1978). Subjects were exposed to two noise levels, 55 and 95 dB A-weighted and performed a primary pursuit motor task and a subsidiary mental arithmetic task. The results indicated that exposure to high levels of noise had detrimental effects on subsidiary task performance. These results were consistent with those of previous researchers (Finkelman & Glass, 1970) and the observed performance decrements may well be due to an environmental overload of subjects' capacities to process information.

In summary, noise stress appears to have two distinct effects on humans. One effect is that noise can distract; the other effect is that noise can arouse the operator. If noise acts to arouse the operator, one might expect improved reaction times and better visual-motor performance under noise stress compared to the ambient, noise-free environment condition.

The literature regarding the effect of acceleration on human performance is, perhaps, more conclusive than that for noise stress. Because of the Space program, much of the acceleration performance work was initiated in the late 1950's and early 1960's. Researchers were interested in determining how man was going to perform while entering and returning from space.

Acceleration and Performance Literature Review

Prior to a review of the pertinent acceleration literature, a definition of body axes accelerations are in order. $+G_z$ acceleration is

that acceleration directed along the individual's z axis, or head-to-toe direction in a standing subject, or along the spine in an upright, seated subject. $+G_x$ acceleration is that directed from the chest to the back; it would be thought of as perpendicular to the spine. G_y acceleration is lateral acceleration and is applied from the left to right or right to left in the subject. A summary of body axes accelerations is provided in Appendix A.

One of the earliest studies involving the effect of acceleration on mental functioning was performed over forty years ago (Kerr & Russell, 1944). In this study, subjects were exposed to levels of acceleration high enough to produce dimming of vision and blackout; attendant impairment of cerebral function was also reported. This effect was observed in subjects who became confused, failed to remember parts of the procedure and suffered loss of control of voluntary movement. The average threshold of unconsciousness was $5G_z$ (unprotected) lasting from 3 to 60 seconds after the centrifuge stopped. Hallenbeck (1946) reported similar findings. He presumed that central nervous system and hence cognitive processes are affected by G levels below those that result in unconsciousness.

Reaction time experiments under G stress were conducted to examine the functioning of higher mental centers. In one experiment (Canfield, Comrey, Wilson, & Zimmerman, 1950) subjects were required to determine the direction that a red light lay in relation to a green one on a panel and to make a response which indicated the proper direction whenever a red light was presented. Acceleration up to 5G had no significant effect on time required for the reaction. Evidence for increased simple reaction time under acceleration, however, was found in a previous

experiment (Canfield, Comrey & Wilson, 1949).

In a discrimination experiment (Warrick & Lund, 1946), errors in dial reading increased as a function of increased acceleration. No significant effects of acceleration were found in another experiment (Canfield, Comrey & Wilson, 1948) which looked at matching one of four similar figures (e.g. ships, clocks, and jugs) in a pattern which exactly matched a central figure. The authors considered these a measure of perceptual speed ability, however, their scores were not expressed in terms of speed but in terms of errors. The subjects (non-pilots) wore anti-G suits and were tested at +1, +2.5 and $+4G_z$ with 15 sec at peak G. Some decrement occurred at $+4G_z$, but only for the first half of the runs each day of the experiment.

Another unknown from the acceleration performance literature was the nature and extent of cognitive *impairment* likely to result from the reduced flow of blood to the brain under acceleration stress. Some studies directed toward this question looked at color discrimination, mathematical skills and short-term memory. Attempts to measure color determination and color naming ability yielded few significant results, at least at $+3G_z$ (Frankenhauser, 1945). Somewhat greater success has been achieved in producing cognitive decrement with tests of simple mathematical skills. Frankenhauser found that the speed of multiplication and subtraction decreases significantly at $+3G_z$. The most thoroughly investigated aspect of high mental performance under acceleration is short-term memory. Numerous experiments by Chambers and his colleagues have shown memory impairment at high $+G_x$ levels (Chambers, 1961; Chambers, 1963; Chambers & Hitchcock, 1963). The results of these studies indicated that acceleration levels up to $+5G_x$ did not

significantly affect performance on memory tasks, measured as the mean percent of correct trials. Acceleration stress greater than $+5G_x$ did reduce memory performance.

Creer (1962) investigated the influence of various acceleration profiles as well as simulated vehicle dynamics upon tracking proficiency. The maximum acceleration magnitudes were $+6G_z$, $+6G_x$, and $-6G_x$ for 2.5 minutes. Creer found that for a relatively easy control task, involving heavily damped (no oscillations or overshoot) vehicle dynamics, no tracking decrement occurred at any acceleration level. In the lightly damped case however, which produced approximately 20% greater errors at one G, performance deteriorated markedly above 4G and was relatively independent of the direction of the acceleration. These results indicated the importance of using a demanding task to show early performance decrement. Another significant point is that control performance is no less effective at $+G_z$ than at $\pm G_x$, provided no serious visual impairment occurs.

Chambers and Hitchcock (1963) also emphasized the importance of the overall difficulty of the respective task and the resulting effect on G-stressed performance; the more inferior the aerodynamic characteristics of the simulated vehicle, the greater the likelihood of inferior human performance under G conditions. By using G levels higher than those in an earlier study, Creer (1962) was able to differentiate clearly between the different vectors, G_x and G_z, employed. All runs lasted 2.5 minutes and vehicle motions were well-damped. Between $+6G_z$ and $+9G_z$ performance dropped rapidly, while only slight decrement was observed from $+1G_x$ up to $+14G_x$. This difference was attributed primarily to the serious visual degradation occuring above $+7G_z$. Significant

decrements in psychomotor performance during accelerations of 5, 7, and $+9G_x$ were found by Little, Hartman and Leverett (1968). Performance decrement was observed with the degree dependent on the level. Successive runs did not result in progressive decrement; after the first run, performance improved and reached an asymptote on runs two and three. Little et al. (1968) observed that (1) performance decrement resulted from either mechanical (limb-loading, etc.) or stress-specific factors rather than physiologic insult and (2) the physiologic responses were clearly short of any objective medical or operational endpoint. Little et al. (1968) recommended that future studies should be directed at defining the point at which the physiological response curve crosses the decrement in psychomotor performance curve in order to define an operational endpoint.

One of the most comprehensive reviews on performance and acceleration was published 16 years ago (Grether, 1971). Grether concluded that both simple and choice reaction times to visual signals generally increased during exposure to $+G_z$ acceleration and that this effect tended to diminish or disappear as subjects became more accustomed to acceleration. Tracking and flight control showed progressive impairment with increasing $+G_z$ acceleration and somewhat less impairment with $+G_x$ acceleration. Intellectual or central nervous functions seem to be more resistant to impairment by acceleration (Grether, 1971).

Tracking performance with G_z protection devices/methods (tilted seats, positive pressure breathing, breathing maneuvers, anti G-suits, weight-training) have been the most popular research topics in the past 15 years. One of the typical experiments involved measuring pilot tracking performance in a high G_z environment as a function of seat back

angle (Rogers, 1973). Rogers found significant improvements in performance as the seat back angle was varied between 30° and 60° from the vertical. This improvement was attributed to increased blood flow to the head (eyes, brain) as a result of minimizing the eye-to-heart blood column. Subject performance was found to be inversely related to the level of G exposure and rapidly deteriorated above $+6G_z$.

In their simulated aerial combat maneuvering (ACM) scenario at the USAF School of Aerospace Medicine centrifuge, Burton and Shaffstall (1978) were unable to repeat the 55% increase in tracking performance reported earlier by Rogers (1973). This discrepancy is attributed to the differences in the tracking tasks used by Rogers and that used by Burton. Loose, McElreath and Potor (1976) found an increase in Root Mean Square error as a function of increasing $+G_z$ in a 2-dimensional tracking task. The task involved combined lateral $+G_y$ and head-to-toe, $+G_z$, motions with 1.6, 3 and $5G_z$ acceleration levels.

More recently, Lisher and Glaister (1978) studied the effects of $+G_z$ acceleration on performance of the Manikin test. This test involves the perception of a figure's orientation with respect to the observer and appears to tap cognitive resources associated with spatial orientation (Carter & Wolstad, 1985). Lisher and Glaister varied acceleration from 1 to $10G_z$ in addition to using three different seat back angles (17, 52, and 67 degrees) from the vertical. Performance on the Manikin test was not affected by $+G_z$ acceleration up to and including $+6G_z$. Seat back angle had a significant effect on performance. Burton and Shaffstall (1980) in a +4.5 to $7.0G_z$ simulated aerial combat maneuvering (ACM) task found no effect for seat back angle on tracking performance but did find that increasing seat back angle improved the subject's G

tolerance. Piranian (1982) investigated pilot tracking performance on a visually-simulated ACM scenario in the Navy centrifuge (Naval Air Development Center, Warminster, PA). The task was to pursue a target aircraft into a $+5G_z$ wind-up, or circling, turn and to hit the target at various G levels. Tracking performance was measured in terms of projected miss distance from the target, percentage of time within 10 mils of the target and pilot opinion ratings. Piranian measured a 20% decrement in performance at 5G compared to 1G which agrees with the trend found by other researchers.

Research by Albery, Ward, and Gill (1985) examined performance in a maze solving task under $+G_z$ acceleration. This task appears to tap resources associated with spatial processing and problem solving. In this study, subjects were exposed from 1.5 to $+6G_z$. In addition to the performance measure, subjective measures of operator workload were obtained with SWAT. The results of this study indicated that performance on the maze-solving task was not significantly affected by $+G_z$ acceleration. However, SWAT showed a systematic increase as a function of $+G_z$ acceleration. The authors concluded "the maze-solving task did not force subjects to work at capacity, and allowed them sufficient processing resources to compensate for the effects of the $+G_z$ stress."

The studies by Albery et al. (1985) and Lisher and Glaister (1978) did not produce $+G_z$ related performance impairment on cognitive tasks up to and including $+6G_z$. These results support Grether's (1971) conclusion that cognitive or intellectual functions are more resistant to the effects of G_z stress relative to visual and motor functions. Alternatively, it is also possible that the tasks utilized by the above researchers may not have imposed sufficient demand on the operator for the

effects of G_z stress to be realized. Research by Repperger (1984) on a compensatory tracking task showed that the addition of $+G_z$ stress increased tracking errors and produced results similar to a more difficult one G tracking task. Repperger (1984) found greater performance decrements as a function of $+G_z$ acceleration for the more difficult tasks relative to the easier tracking tasks.

FIGURE 1

DYNAMIC ENVIRONMENT SIMULATOR
(DES)

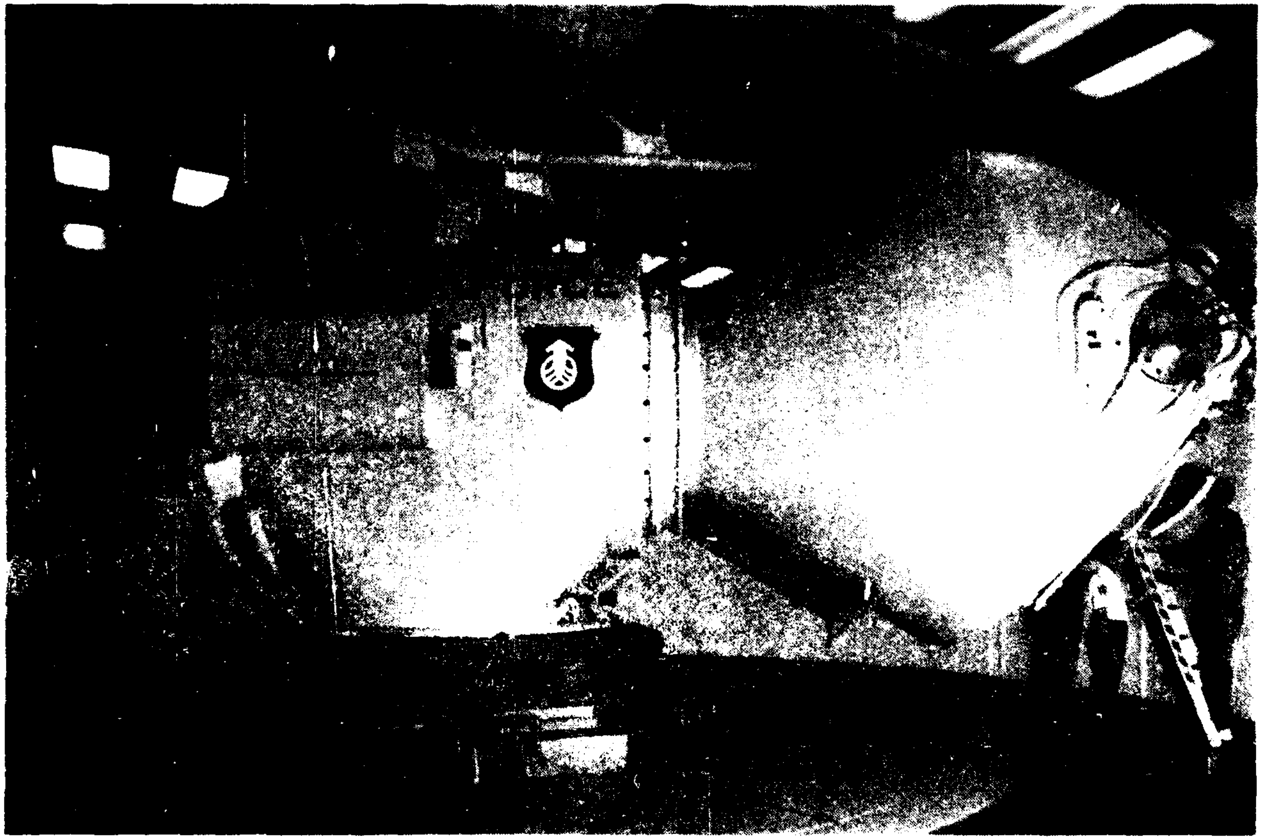
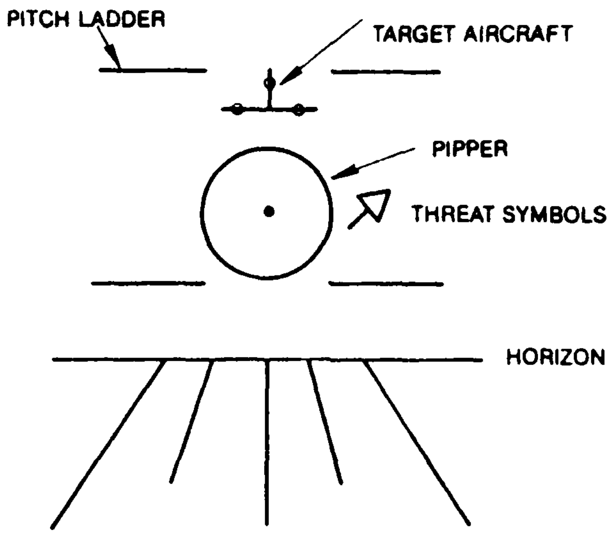


FIGURE 2

DUAL TASK DISPLAY



THREAT SYMBOLS	COMPLEX RESPONSE	TRIM SWITCH RESPONSE	NONTHREAT SYMBOLS
FCR	ECM	UP	
SAM	CHAFF	DOWN	
SAM	FLARES	RIGHT	
SAM	CHAFF/FLARES	LEFT	

FIGURE 3

PRESENT DES SYSTEM CONFIGURATION

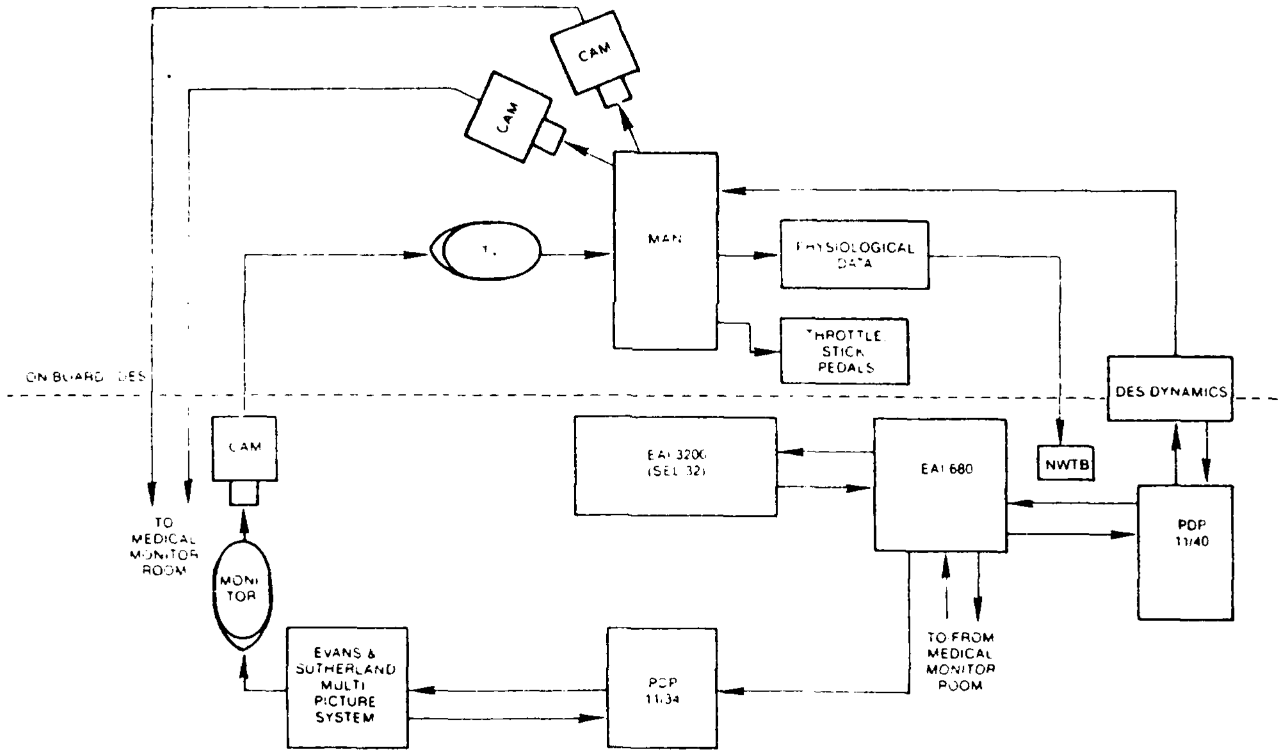


FIGURE 4
DES CAB LAYOUT FOR TRACKING

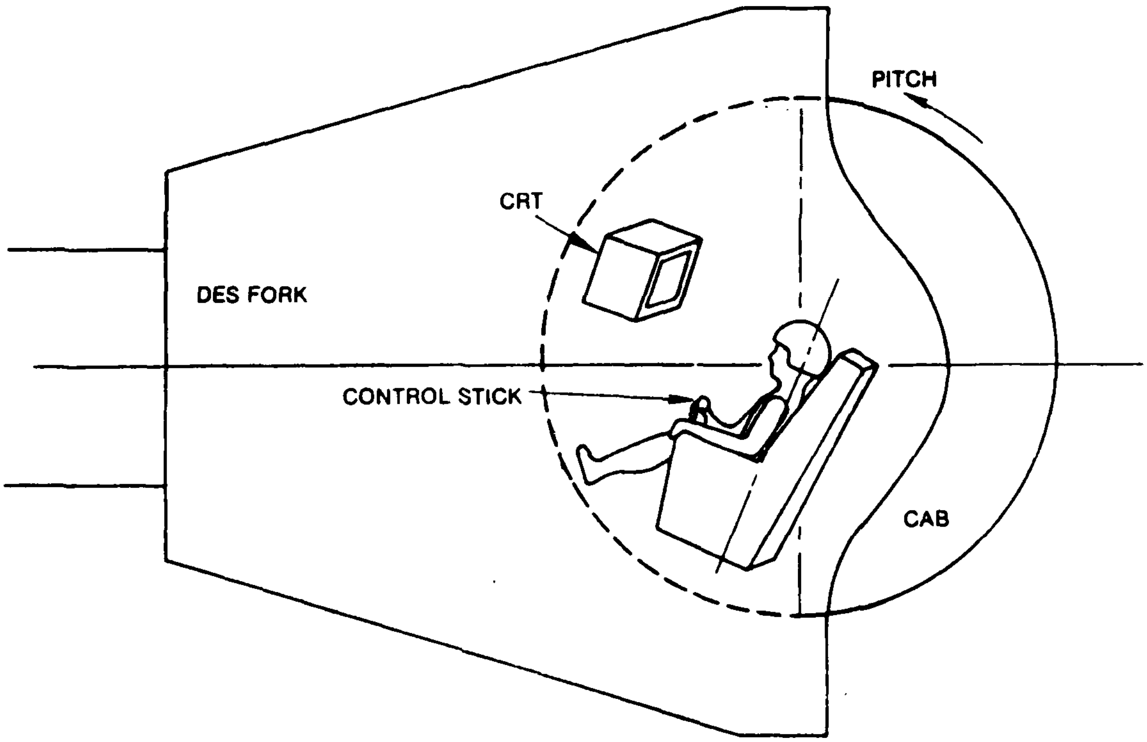


FIGURE 5

VIDEO DOT GENERATOR AND TRIGGER SIGNAL

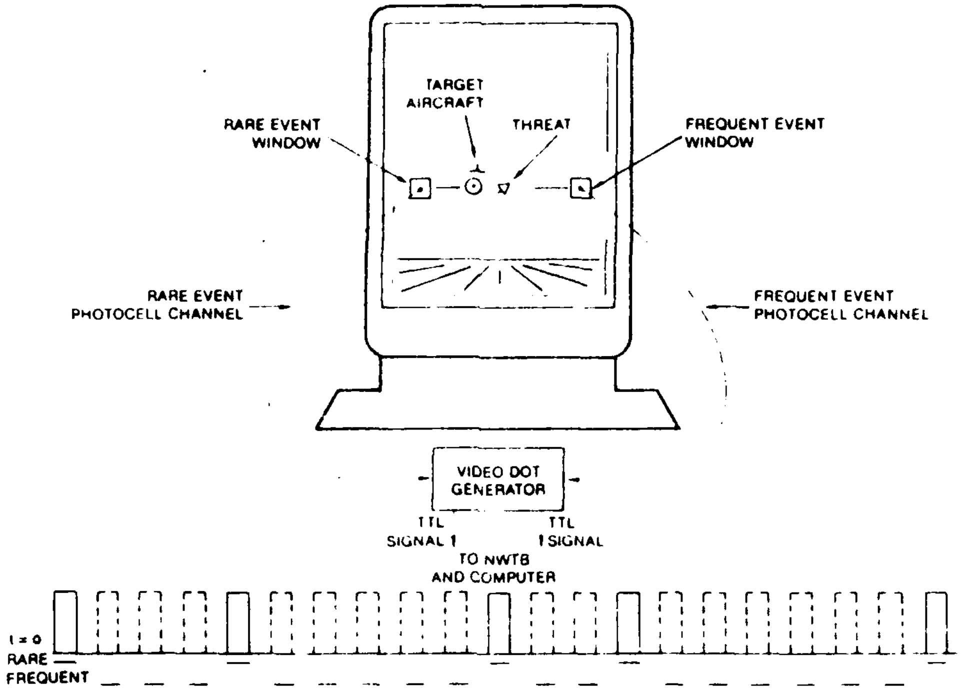


FIGURE 6. FULLY INSTRUMENTED SUBJECT

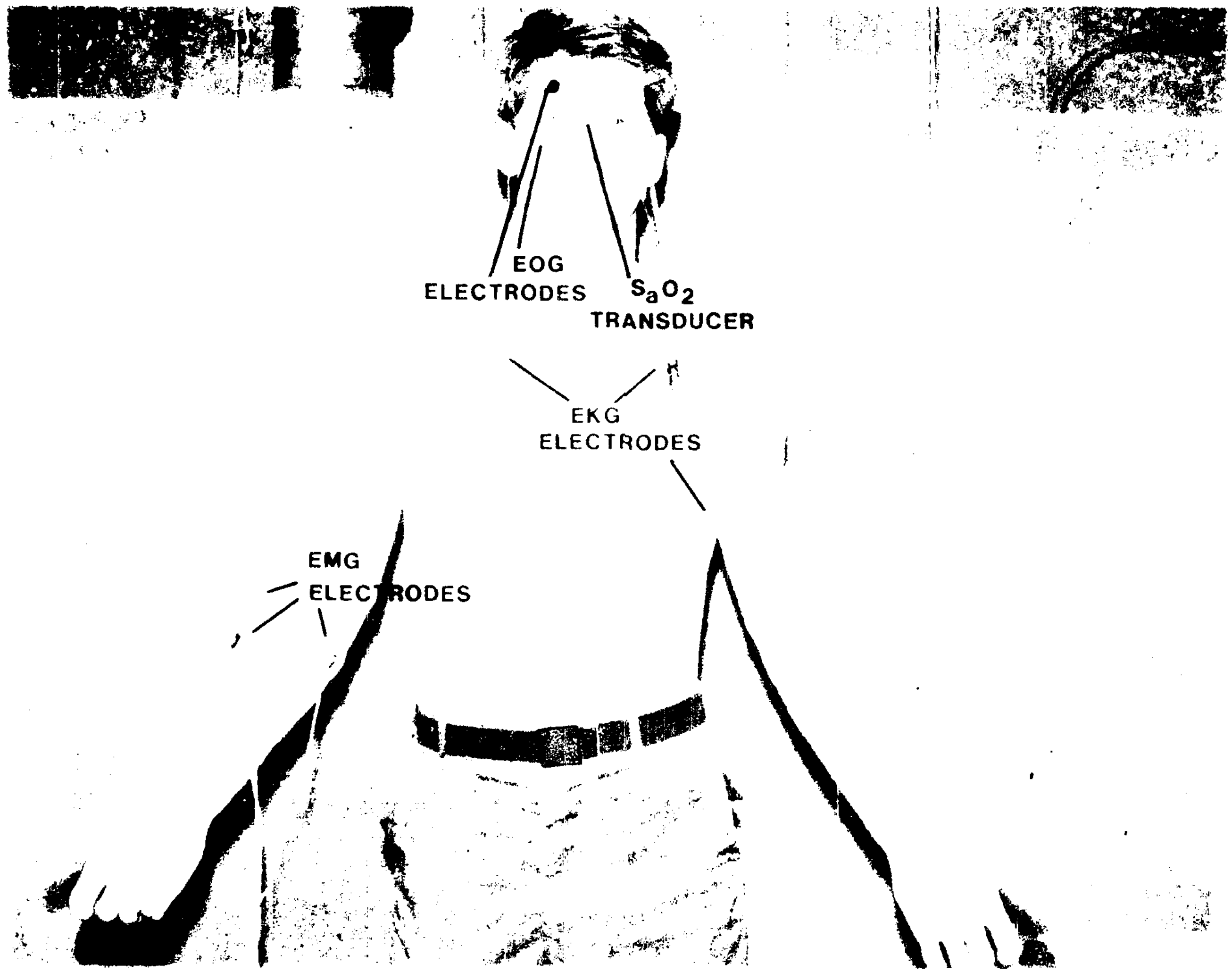


FIGURE 7

ELECTRODE TO NWTB INTERFACES

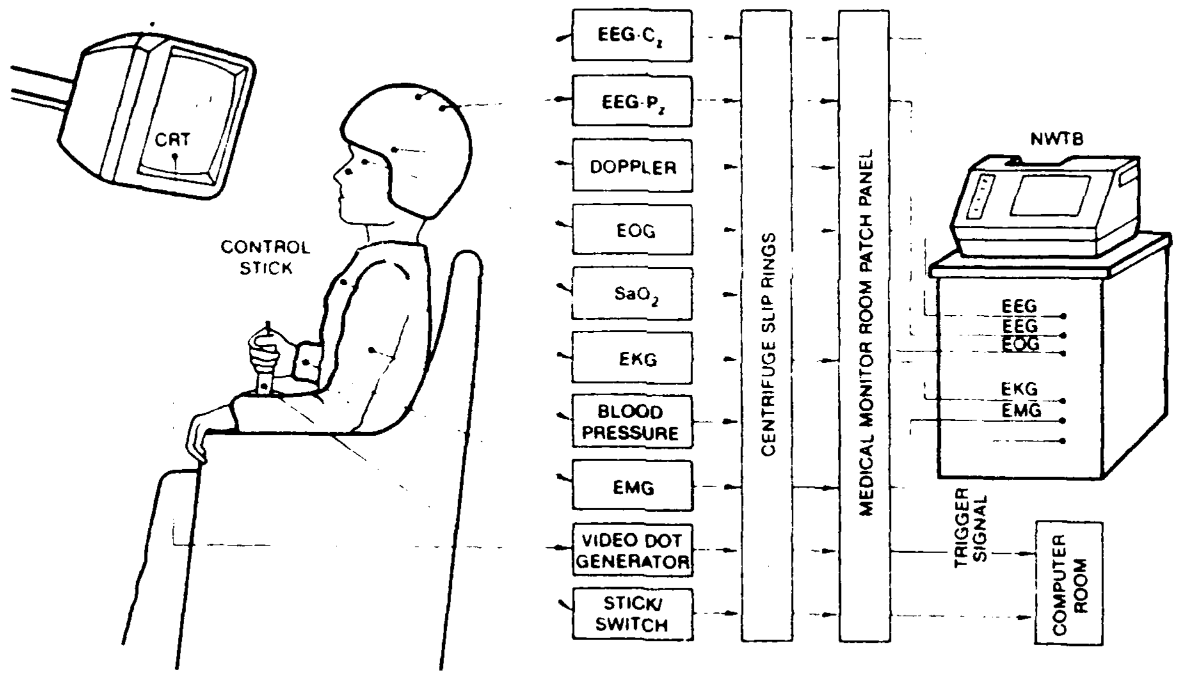
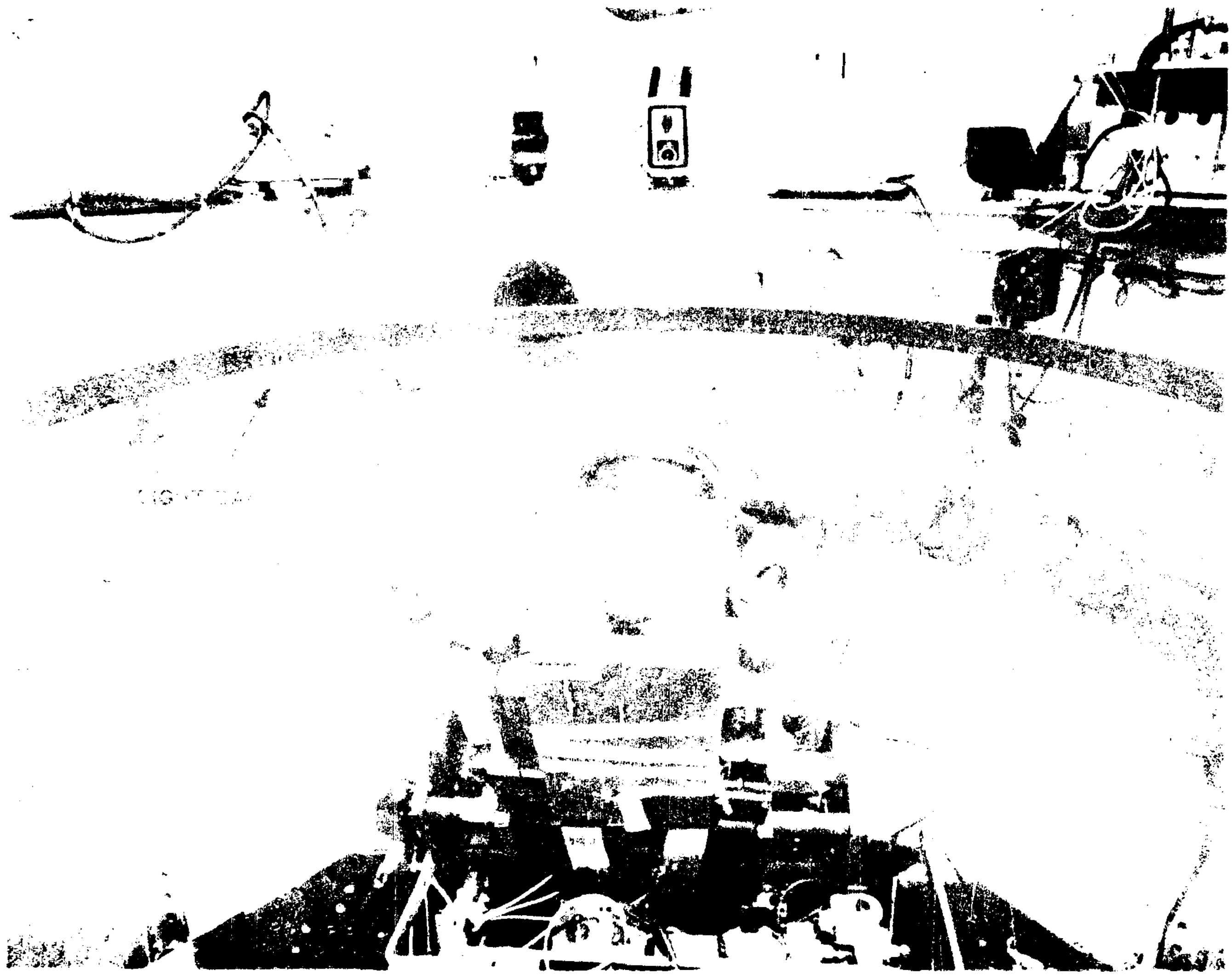


FIGURE 8. SUBJECT IN THE DES CAB



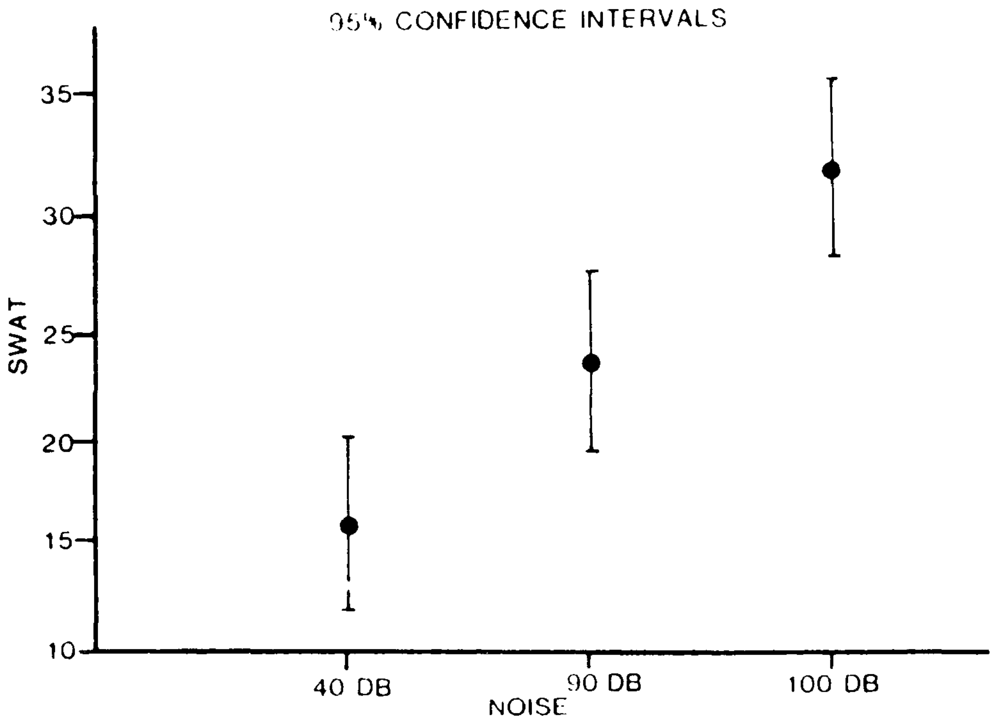


FIGURE 9a. SWAT VS. NOISE AVERAGED ACROSS TASK

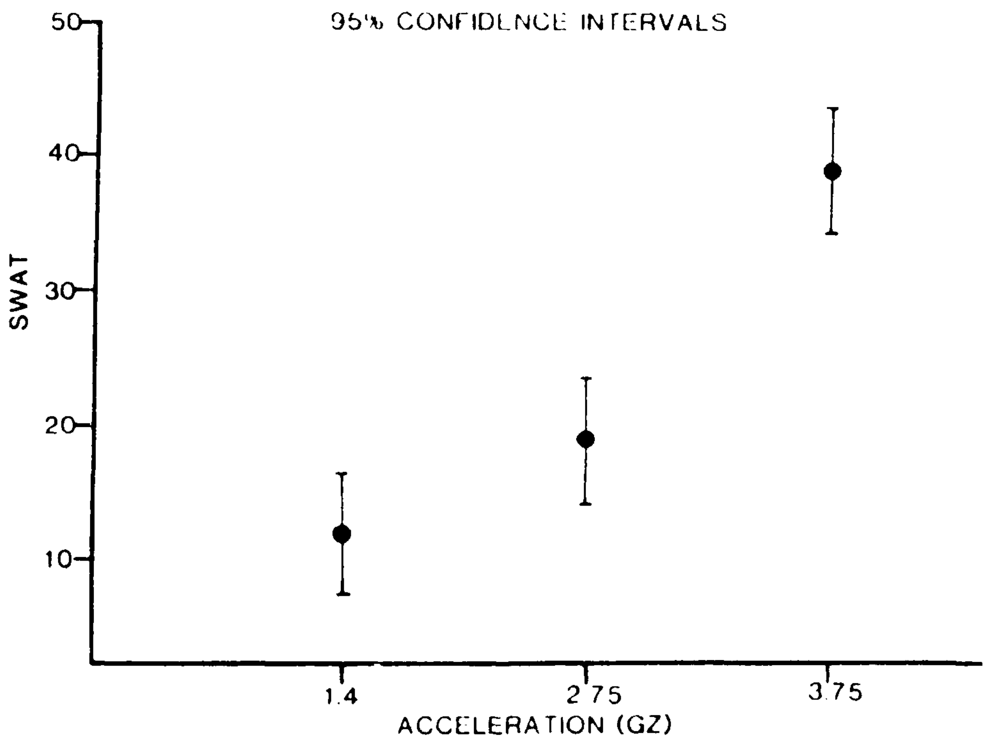


FIGURE 9b. SWAT VS. ACCELERATION AVERAGED ACROSS TASK

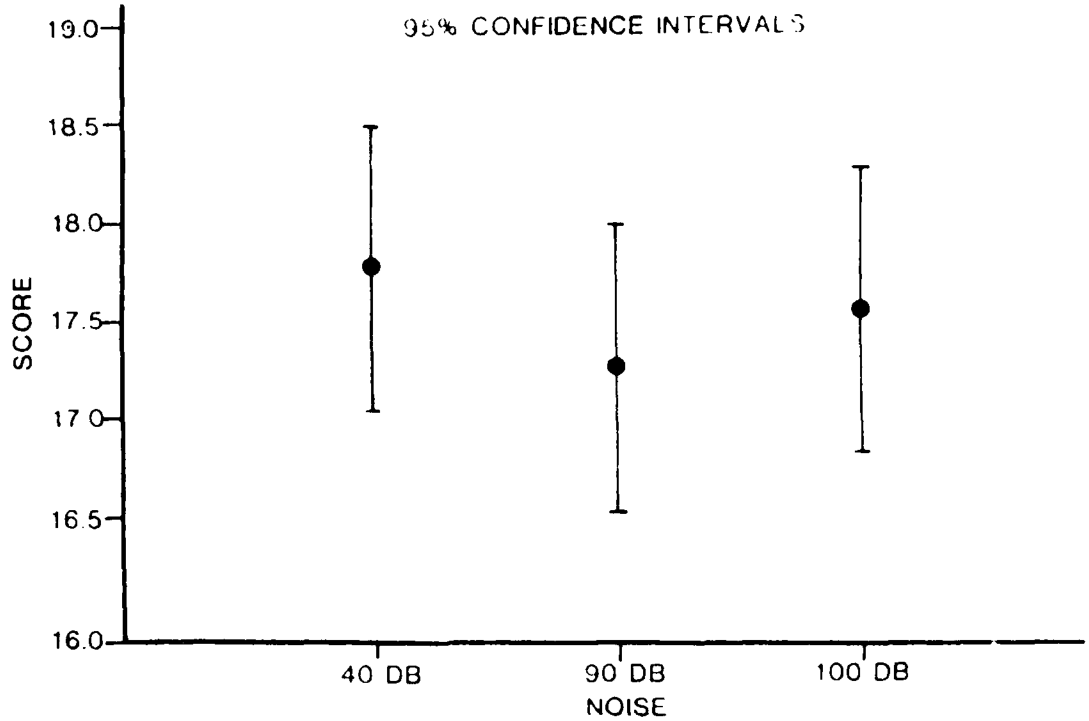


FIGURE 10a. PRIMARY TRACKING TASK ERROR SCORE VS. NOISE AVERAGED ACROSS TASK

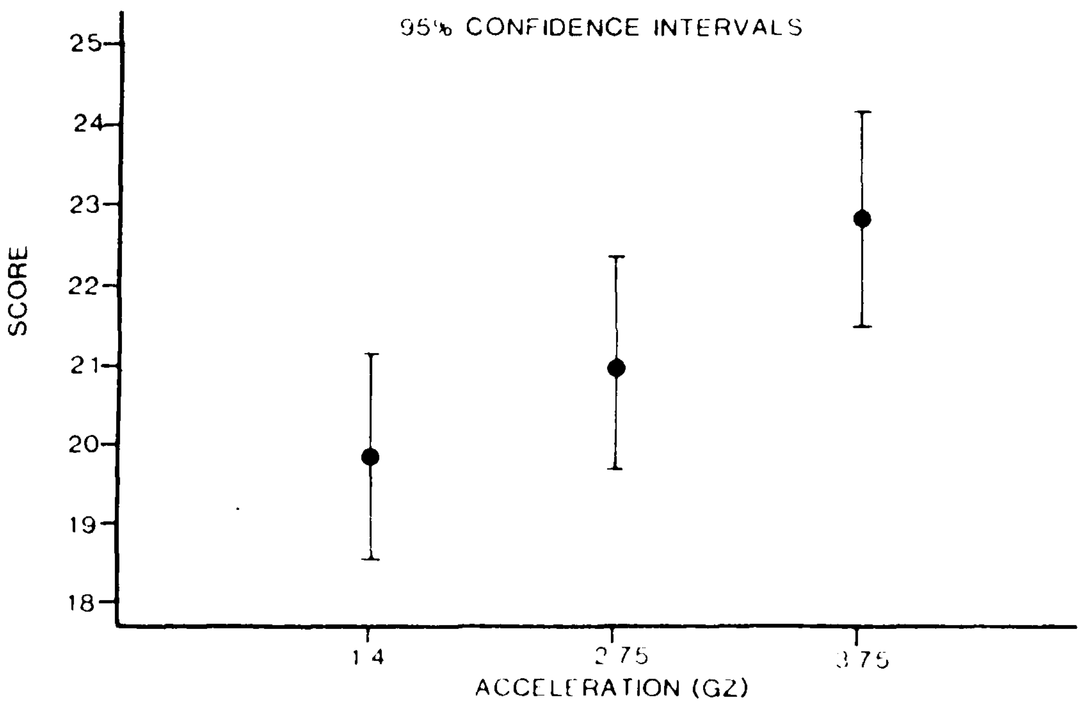
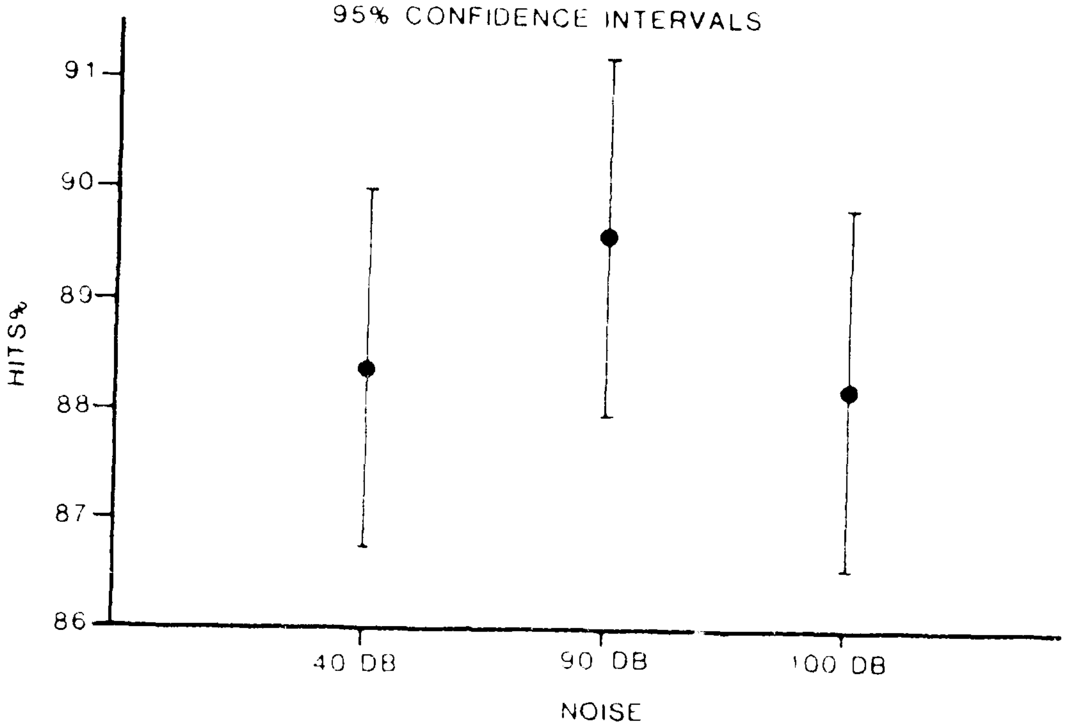


FIGURE 10b. PRIMARY TRACKING TASK ERROR SCORE VS. ACCELERATION AVERAGED ACROSS TASK



11a. SECONDARY TASK PERFORMANCE VS NOISE AVERAGED ACROSS TASK

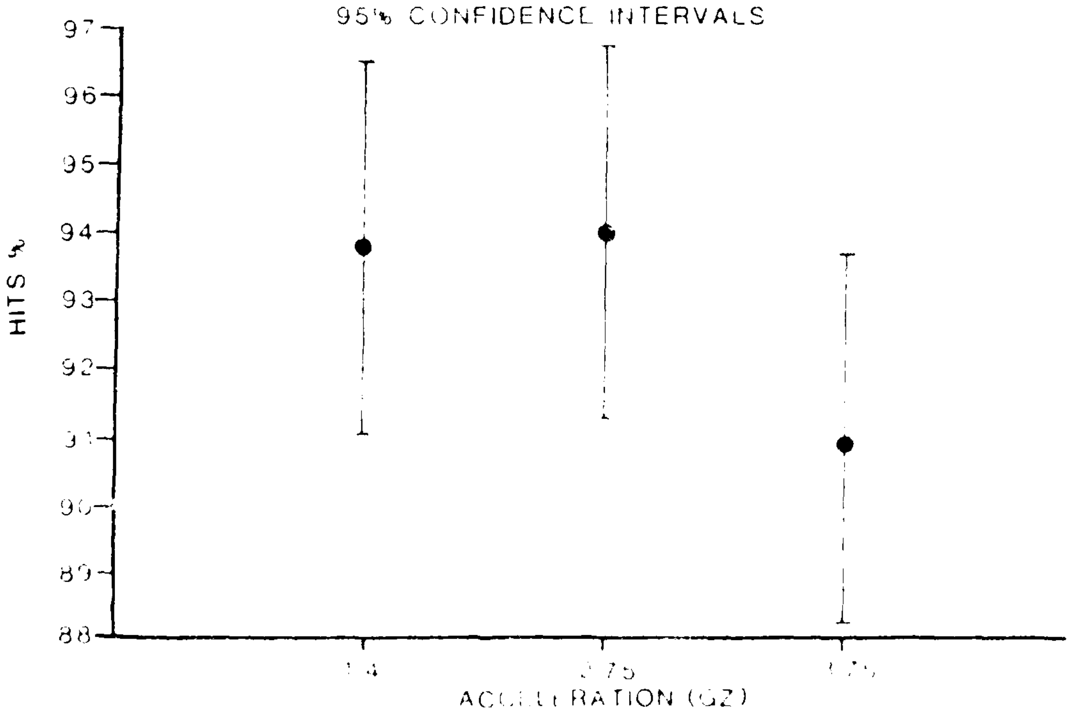


FIGURE 11b SECONDARY TASK PERFORMANCE VS ACCELERATION AVERAGED ACROSS TASK

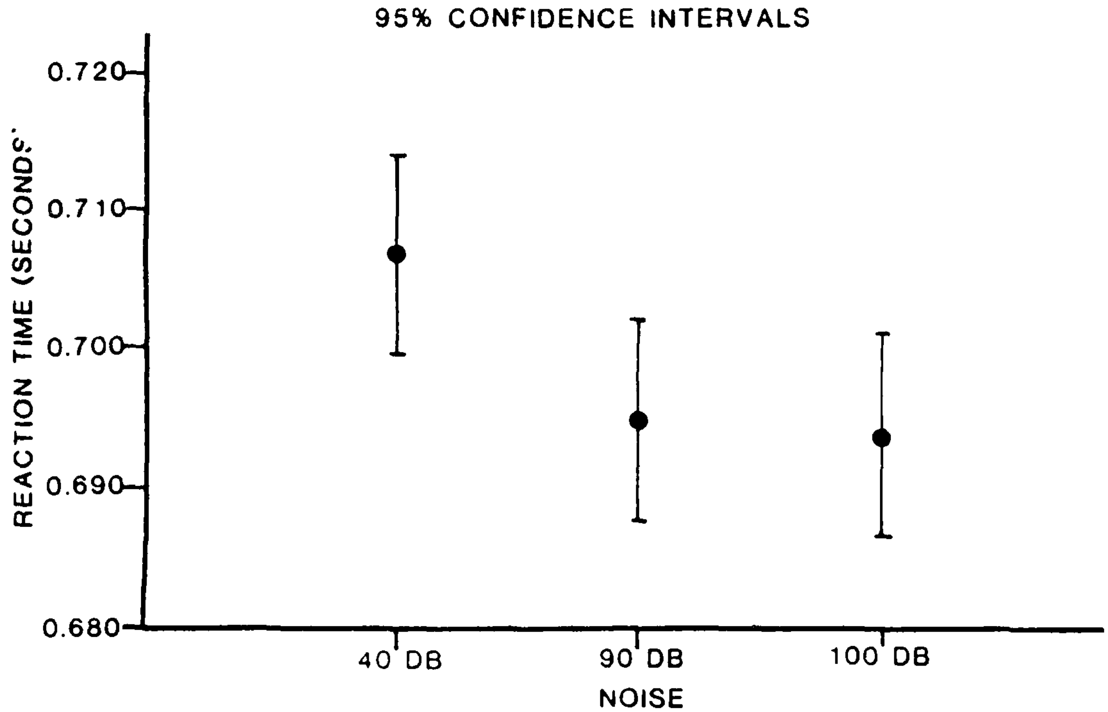


FIGURE 12a. SECONDARY TASK REACTION TIME VS. NOISE AVERAGED ACROSS TASK

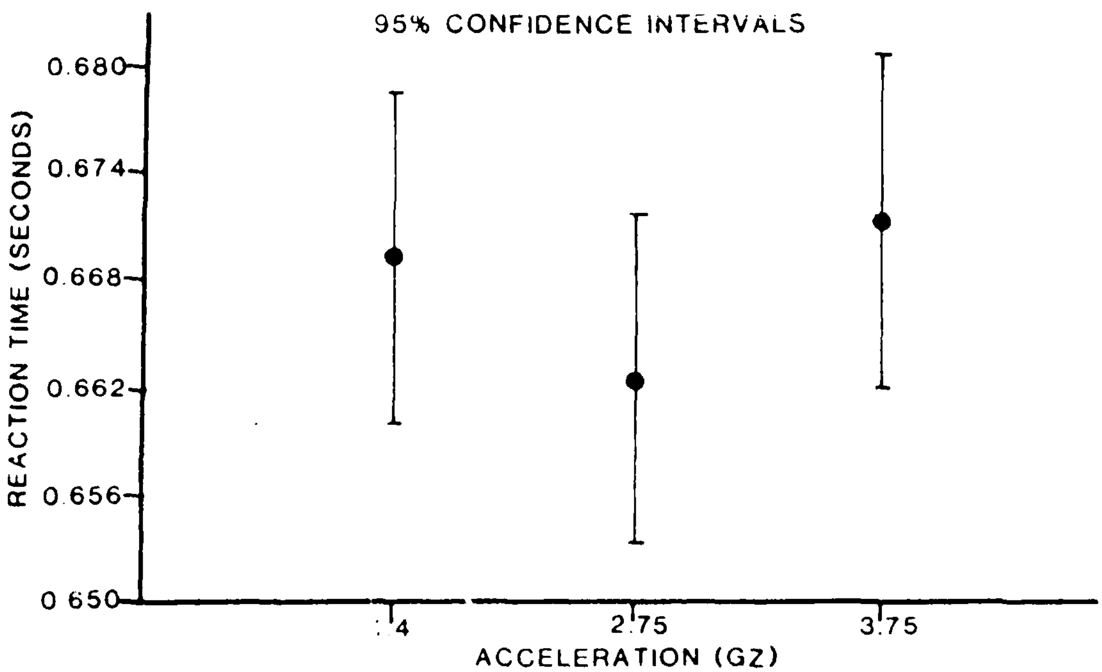


FIGURE 12b. SECONDARY TASK REACTION TIME VS. ACCELERATION AVERAGED ACROSS TASK

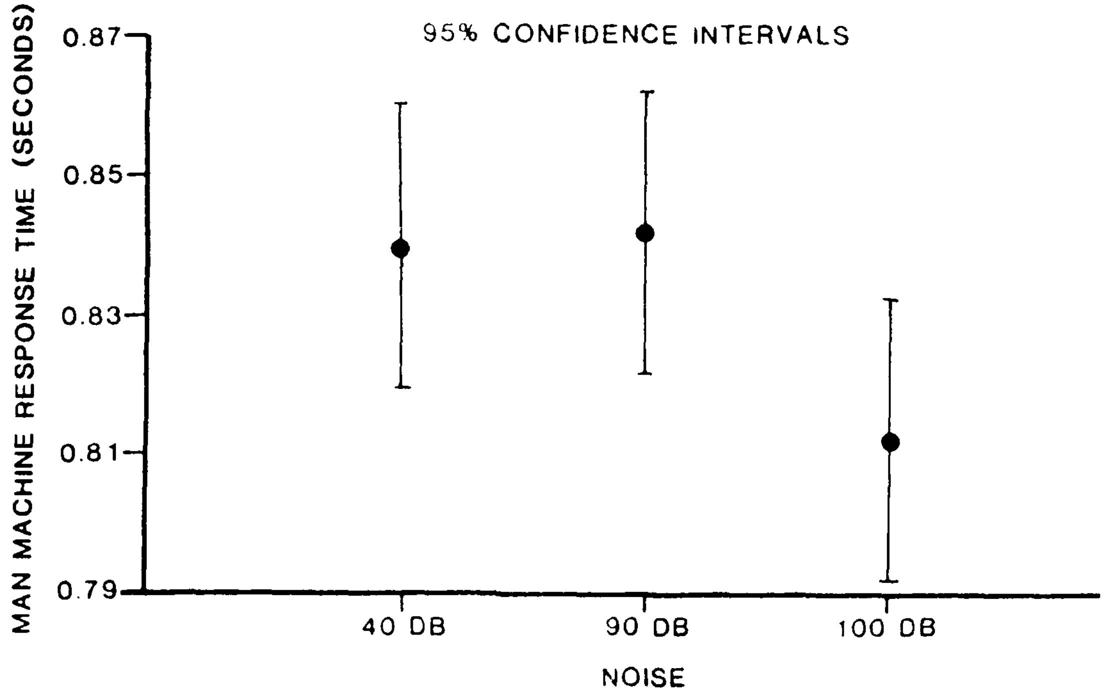


FIGURE 13a. MAN-MACHINE RESPONSE TIME VS. NOISE AVERAGED ACROSS TASK

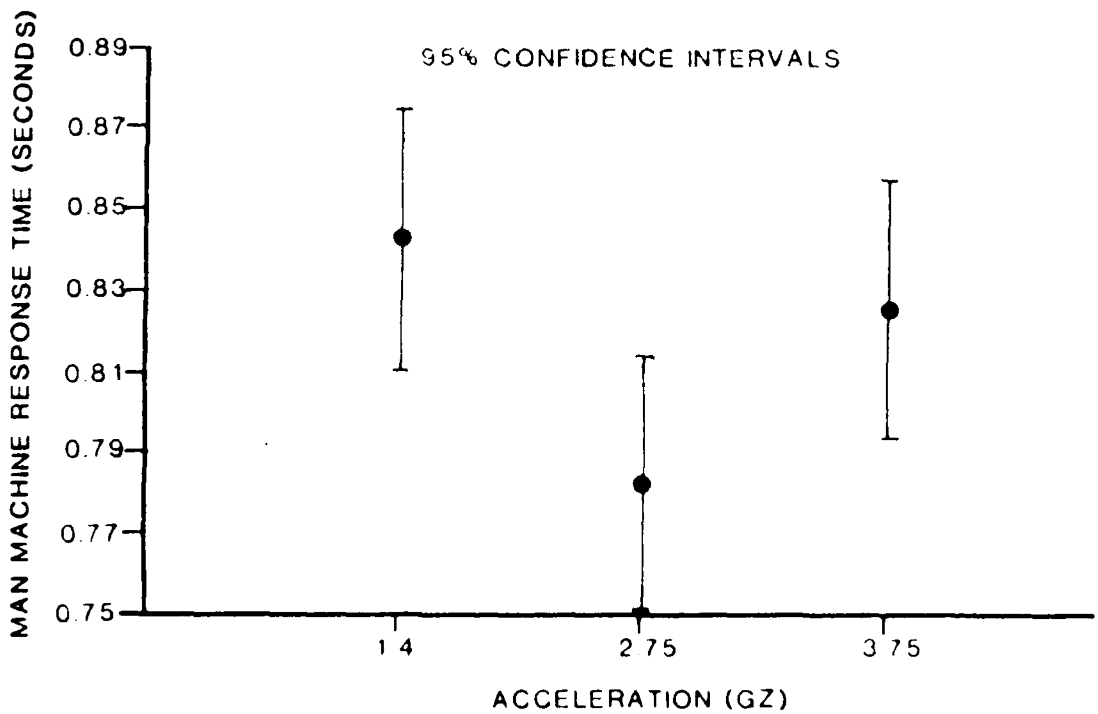


FIGURE 13b. MAN-MACHINE RESPONSE TIME VS. ACCELERATION AVERAGED ACROSS TASK

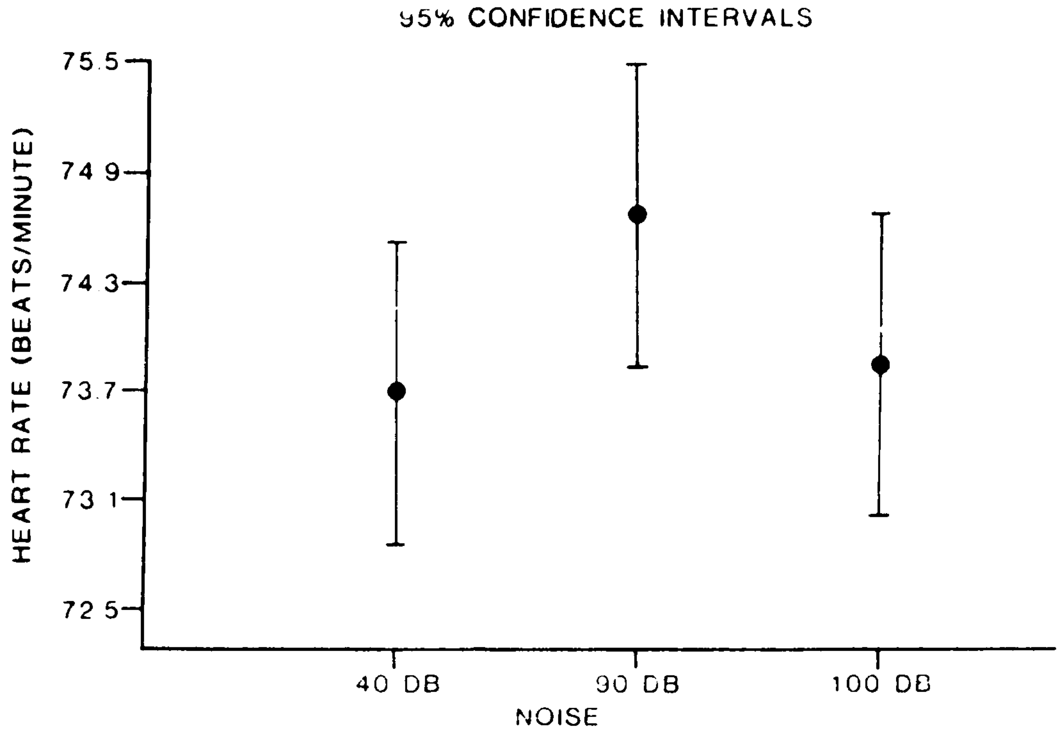


FIGURE 14a HEART RATE VS. NOISE AVERAGED ACROSS TASK

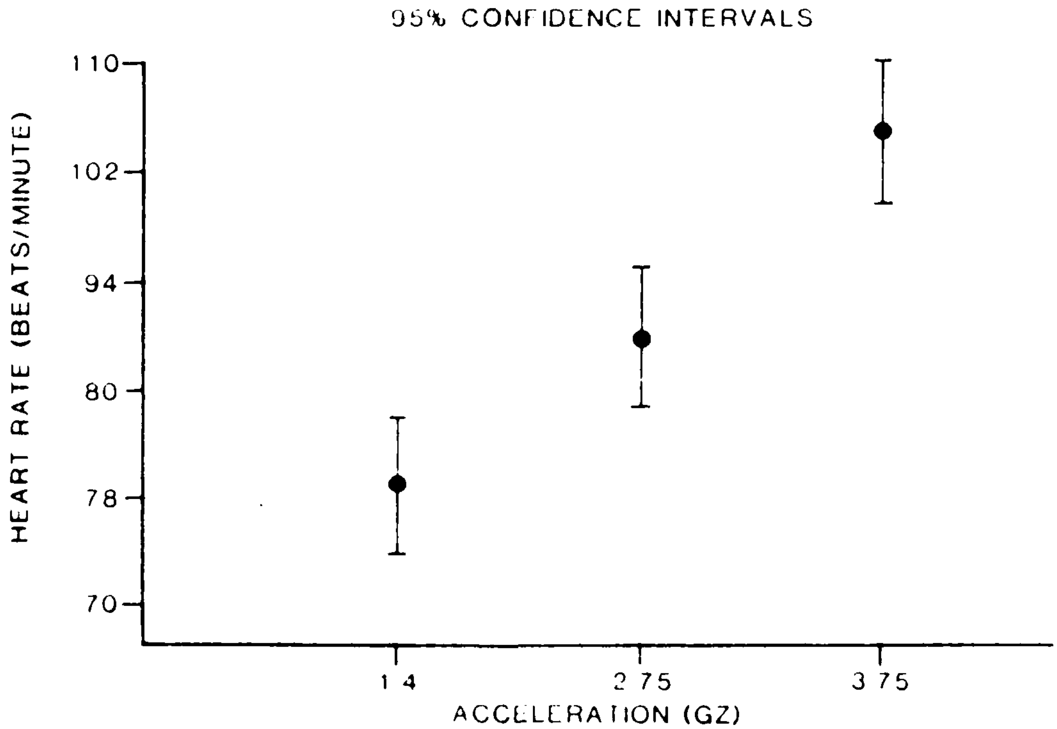


FIGURE 14b HEART RATE VS. ACCELERATION AVERAGED ACROSS TASK

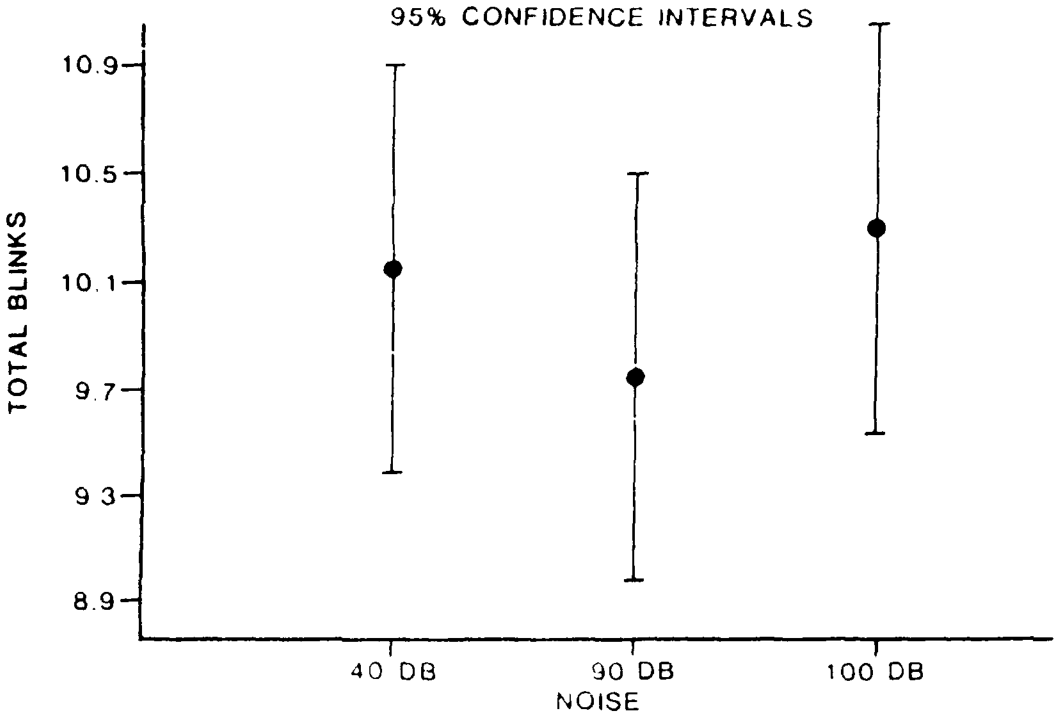


FIGURE 15a. TOTAL EYE BLINKS VS. NOISE AVERAGED ACROSS TASK

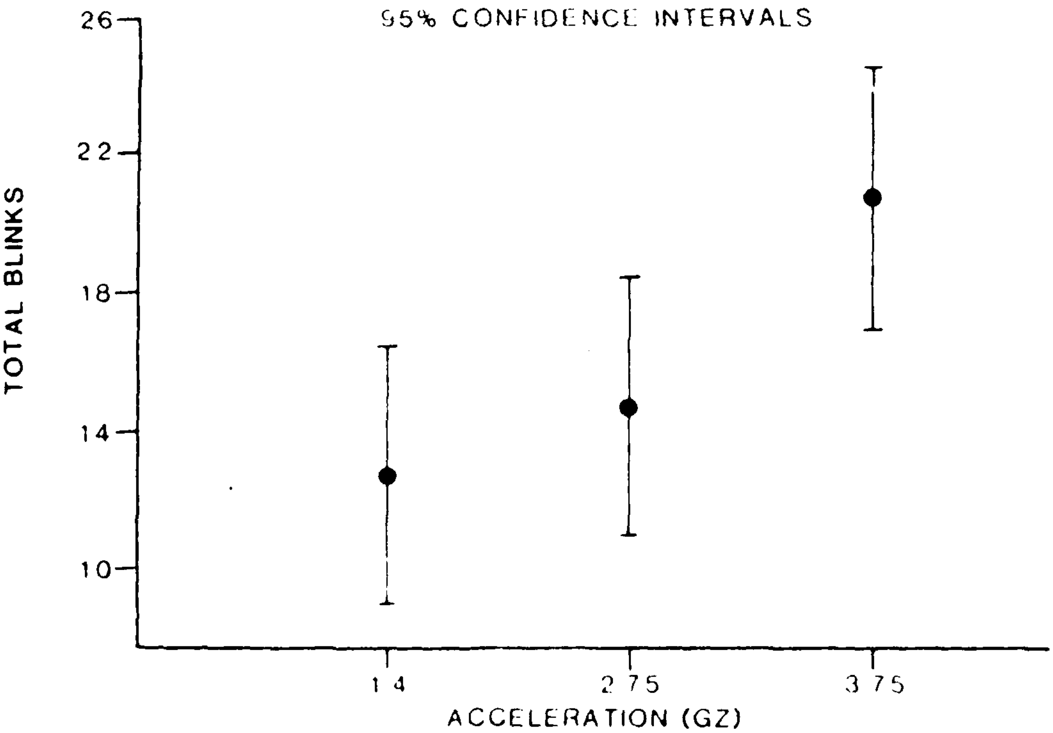


FIGURE 15b. TOTAL EYE BLINKS VS. ACCELERATION AVERAGED ACROSS TASK

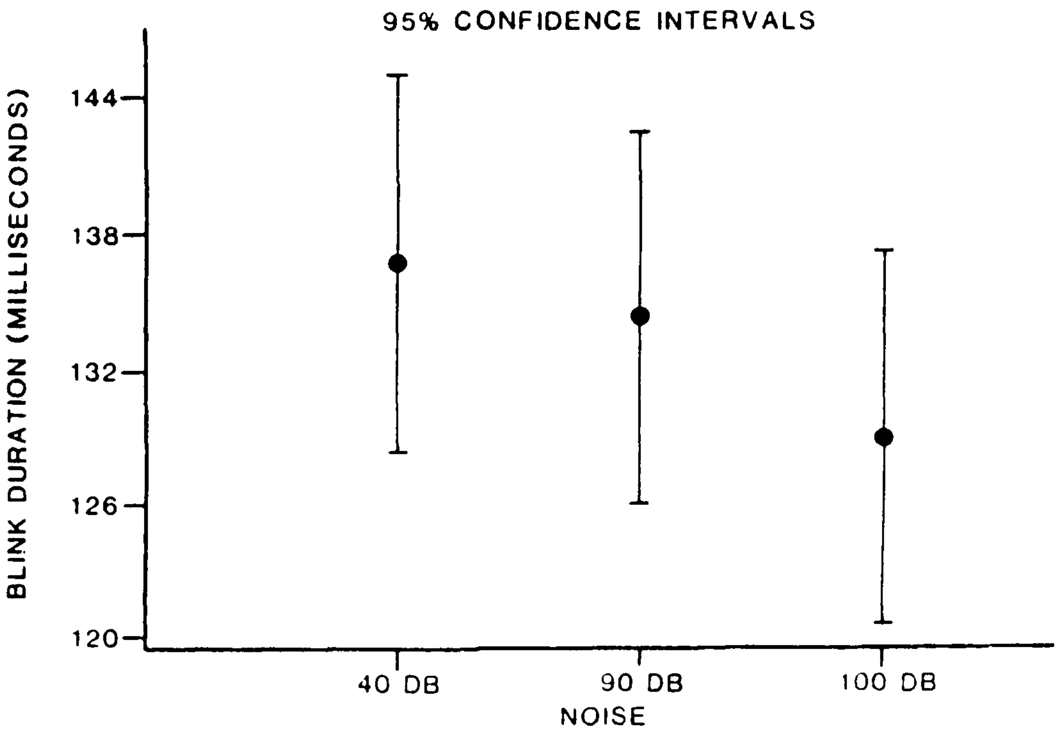


FIGURE 16a. EYE BLINK DURATION VS. NOISE AVERAGED ACROSS TASK

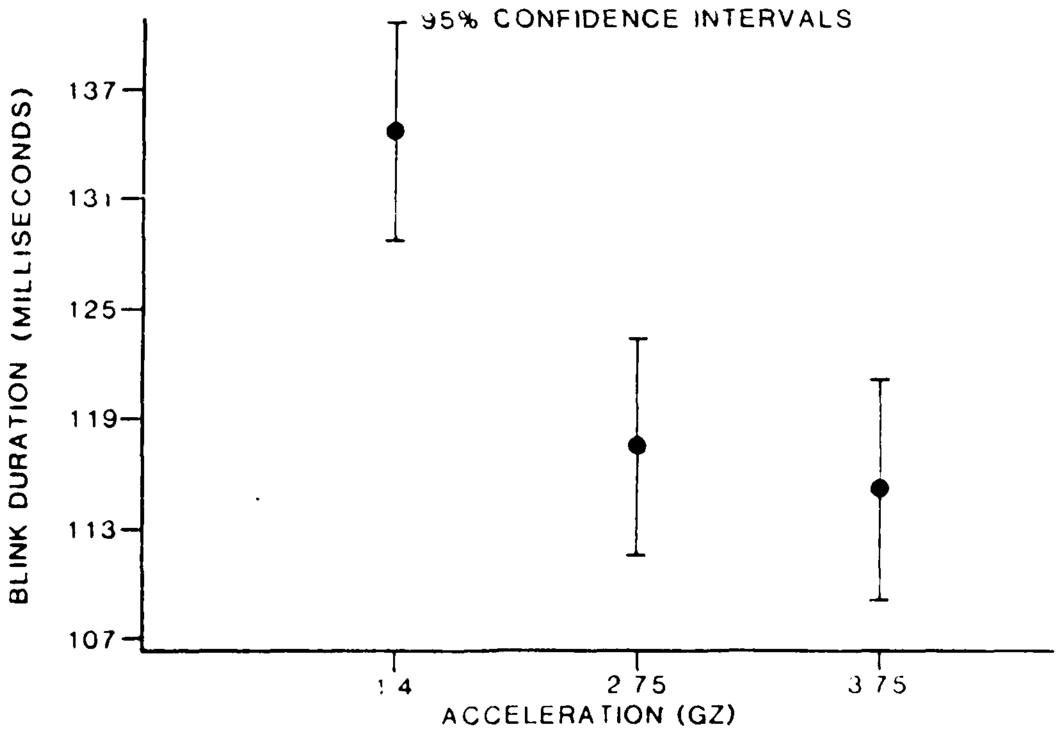


FIGURE 16b. EYE BLINK DURATION VS. ACCELERATION AVERAGED ACROSS TASK

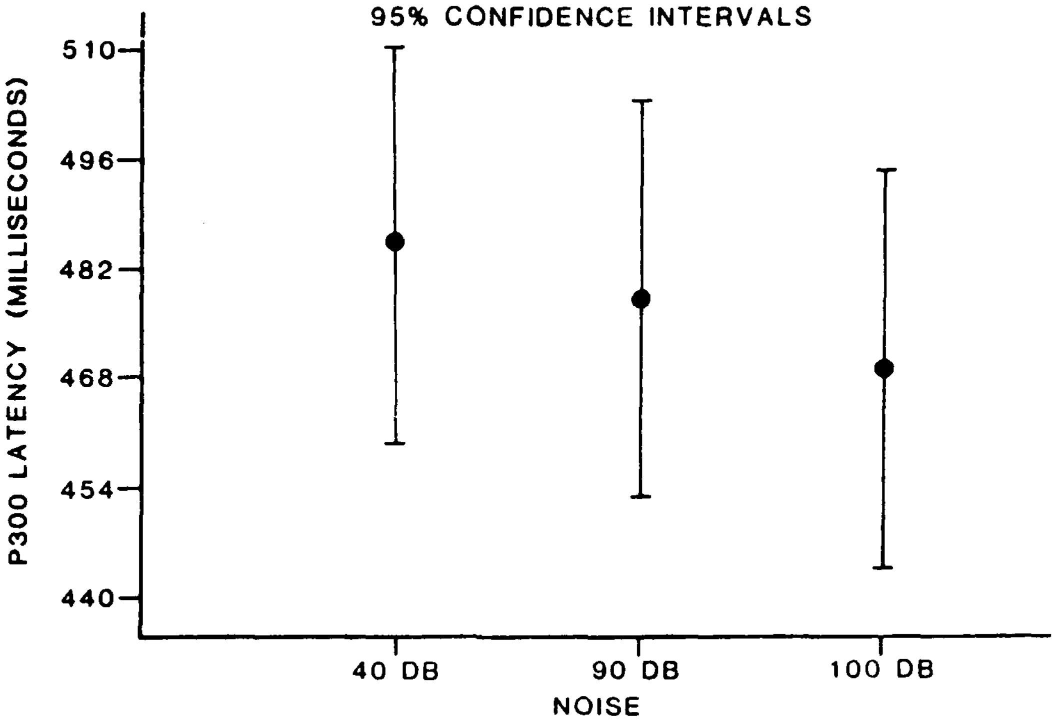


FIGURE 17a. P300 LATENCY VS. NOISE AVERAGED ACROSS TASK

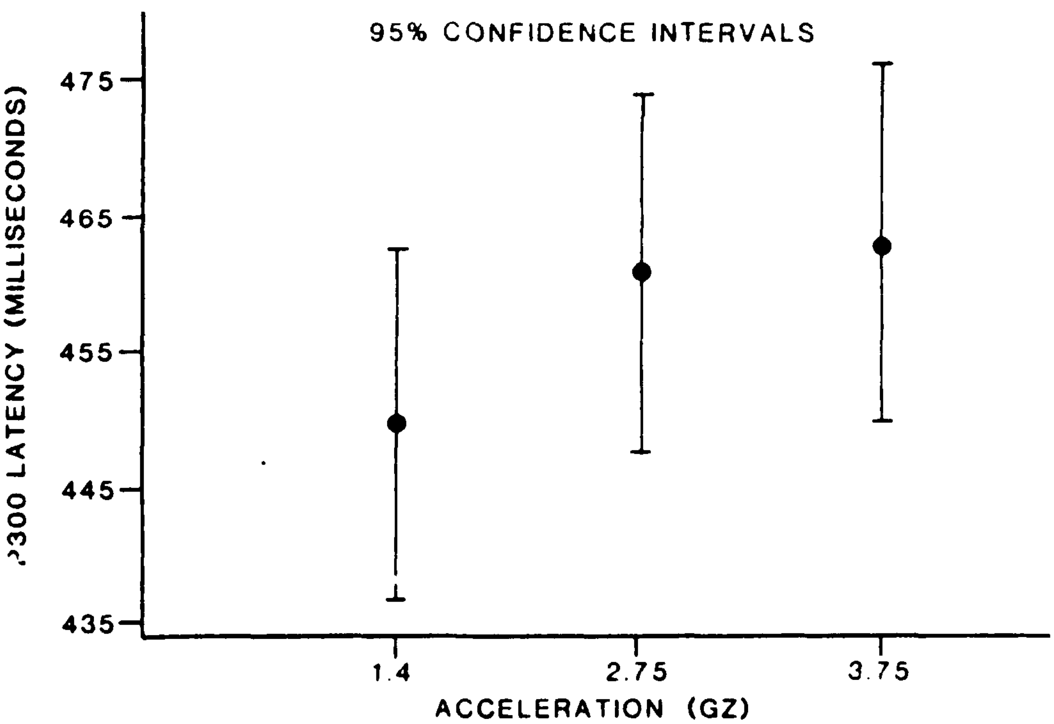


FIGURE 17b. P300 LATENCY VS. ACCELERATION AVERAGED ACROSS TASK

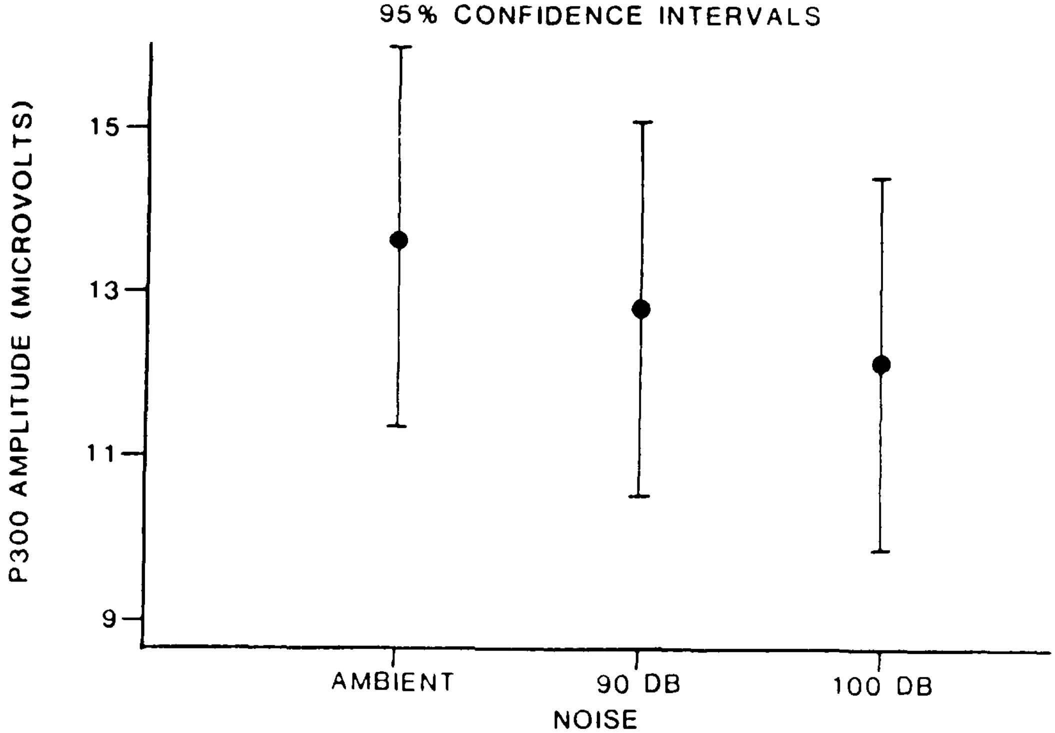


FIGURE 18a. P300 AMPLITUDE VS. NOISE AVERAGED ACROSS TASK

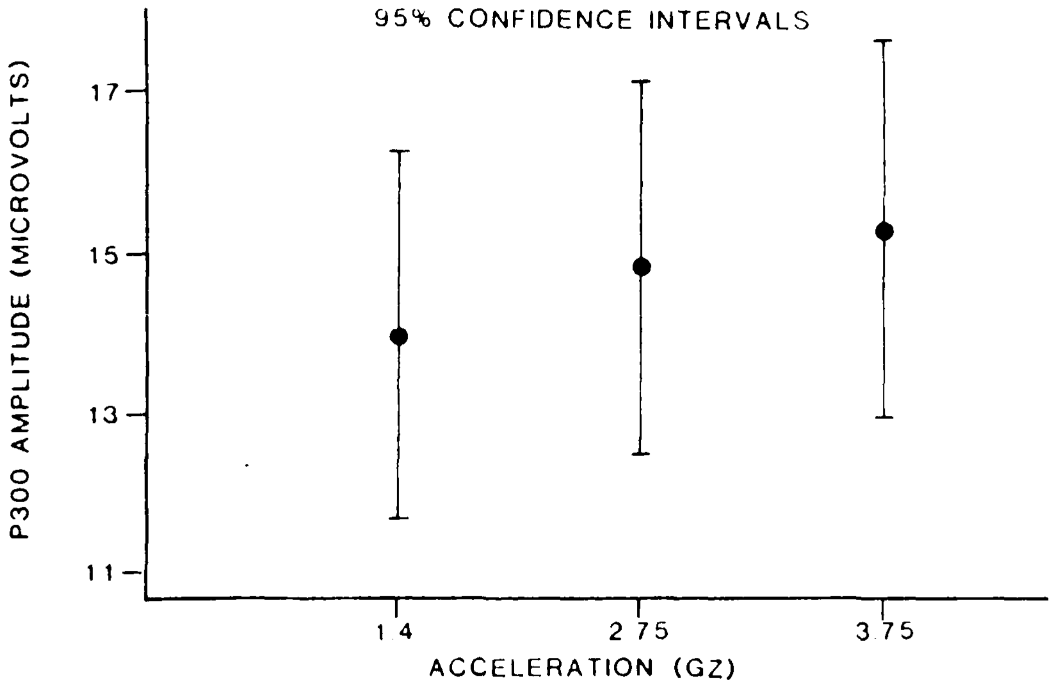


FIGURE 18b. P300 AMPLITUDE VS. ACCELERATION AVERAGED ACROSS TASK

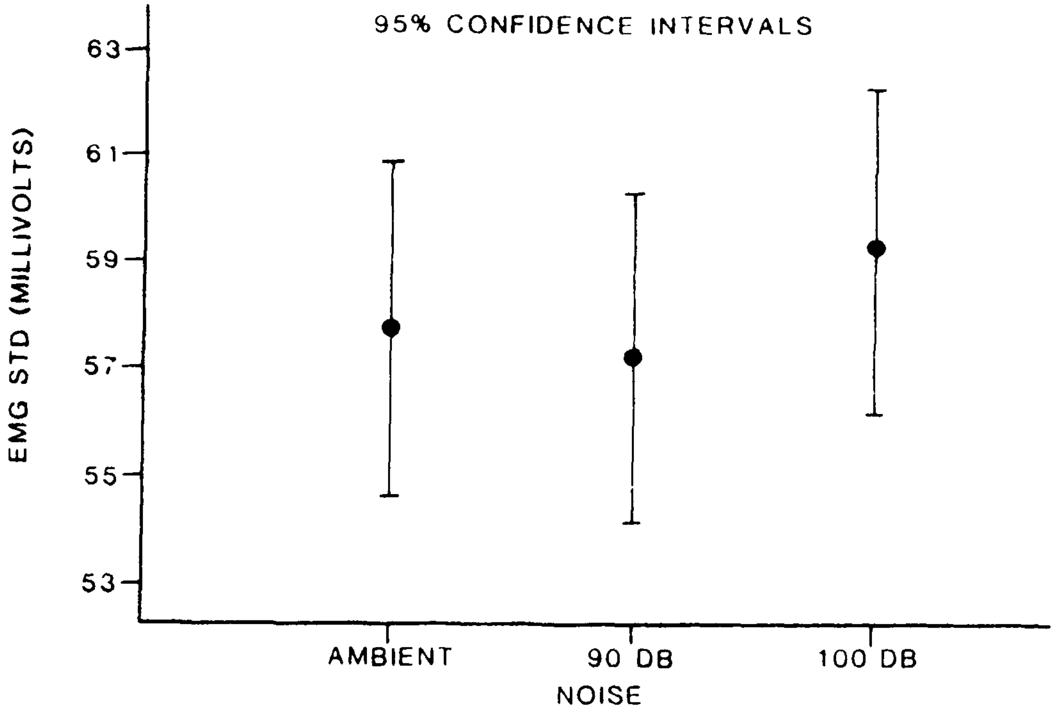


FIGURE 19a. EMG STANDARD DEVIATION VS. NOISE AVERAGED ACROSS TASK

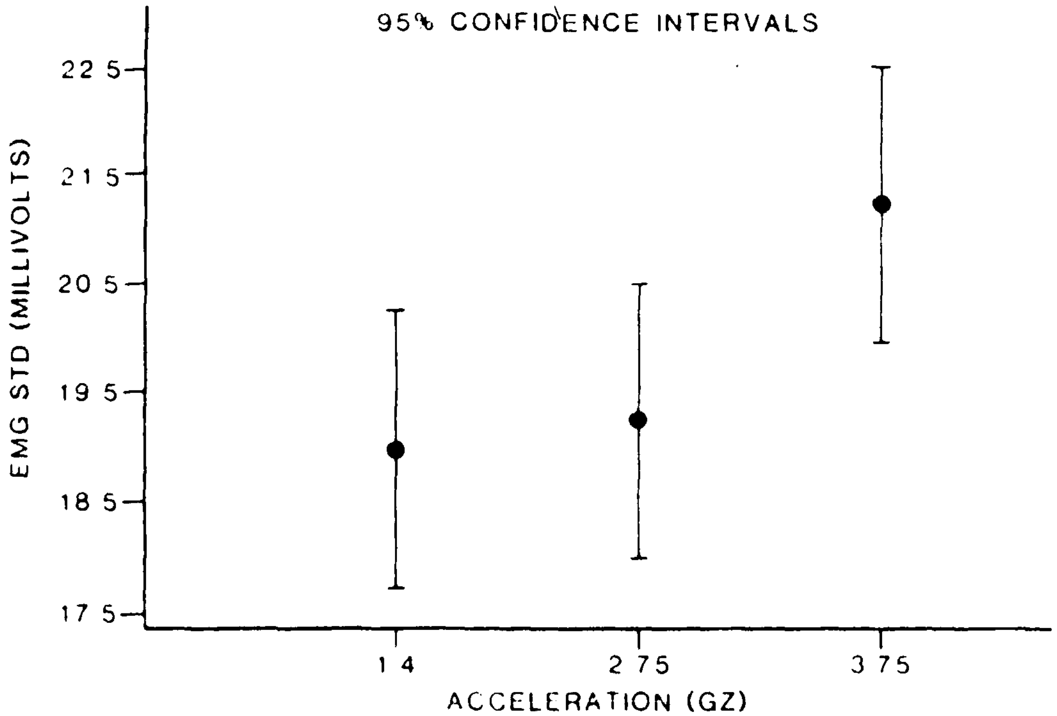


FIGURE 19b. EMG STANDARD DEVIATION VS. ACCELERATION AVERAGED ACROSS TASK

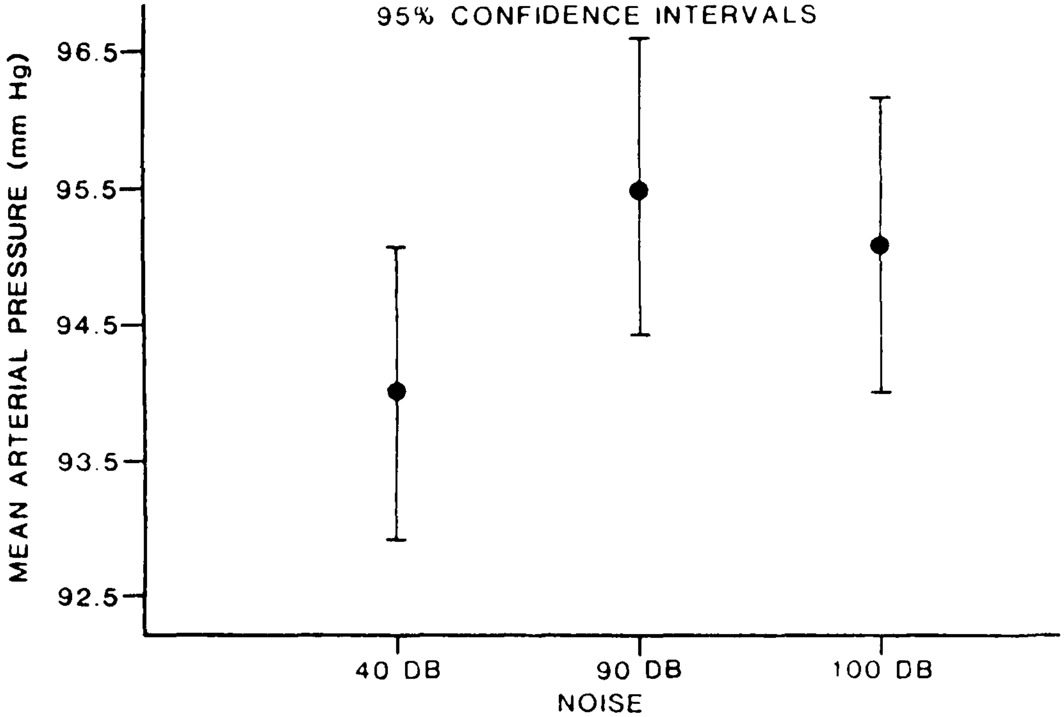


FIGURE 20. MEAN ARTERIAL BLOOD PRESSURE VS. NOISE AVERAGED ACROSS TASK

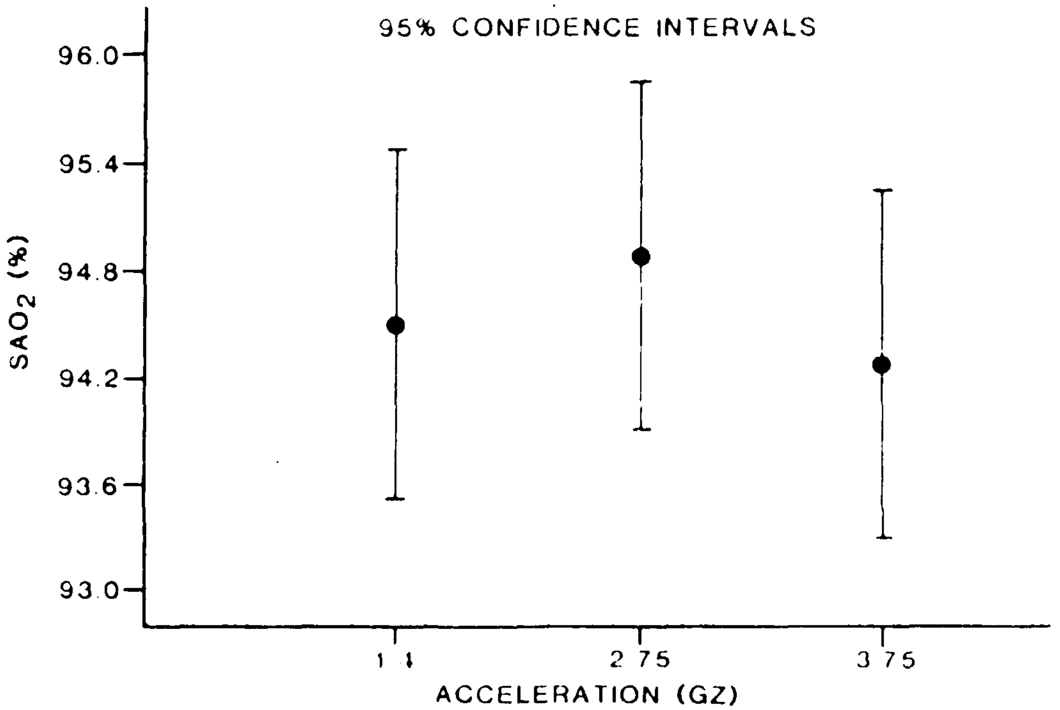


FIGURE 21. PERCENT ARTERIAL OXYGEN SATURATION VS. ACCELERATION AVERAGED ACROSS TASK

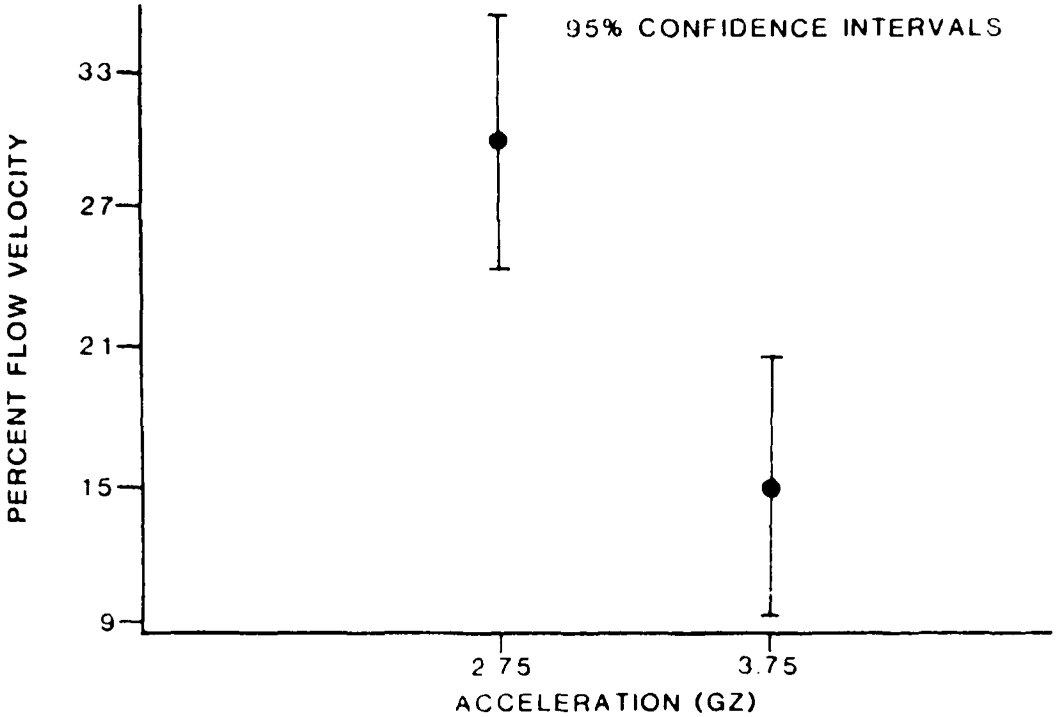


FIGURE 22. PERCENT TEMPORAL ARTERY FLOW VELOCITY VS. ACCELERATION AVERAGED ACROSS TASK

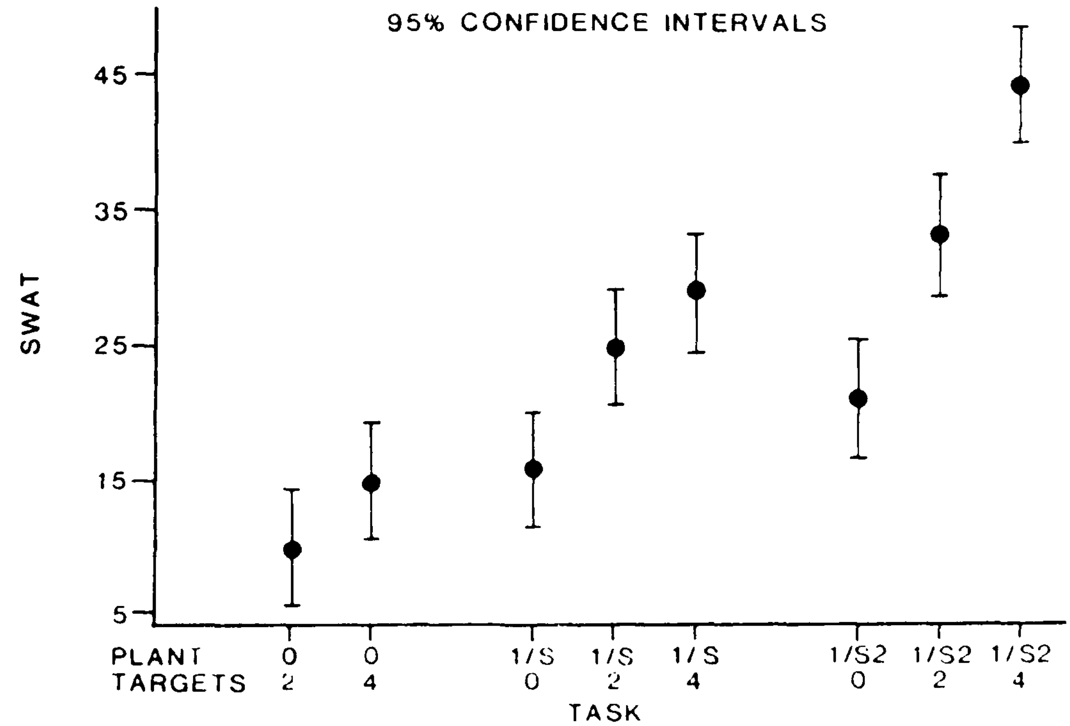


FIGURE 23a. SWAT VS. TASK AVERAGED ACROSS NOISE

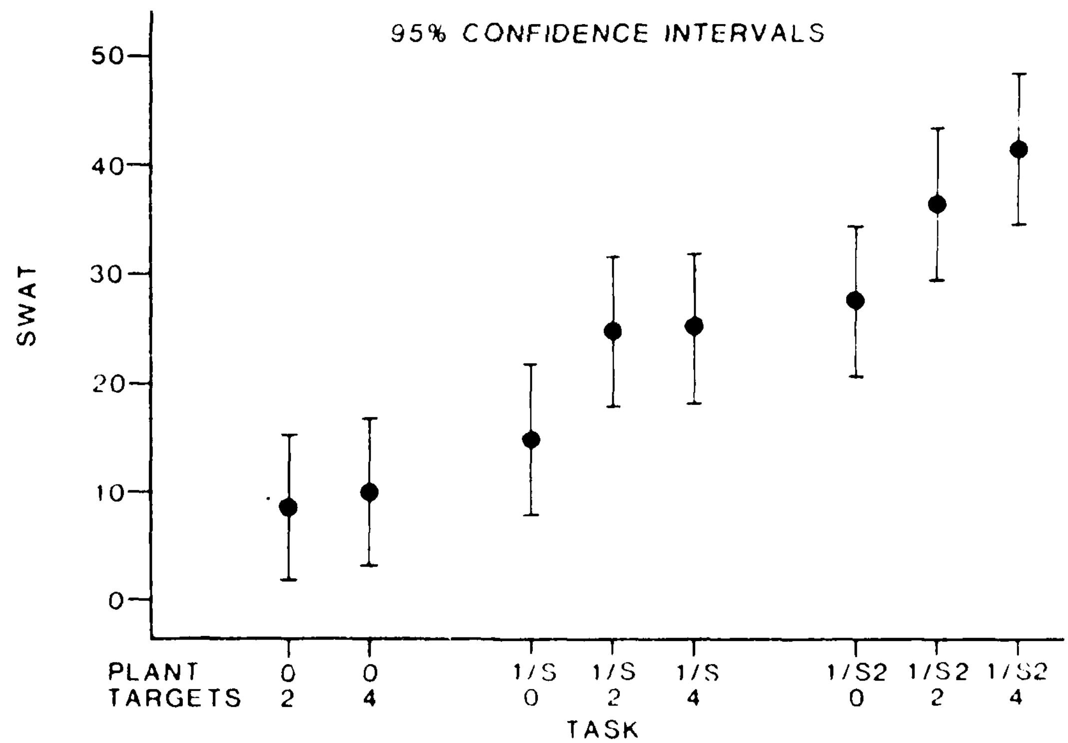


FIGURE 23b. SWAT VS. TASK AVERAGED ACROSS ACCELERATION

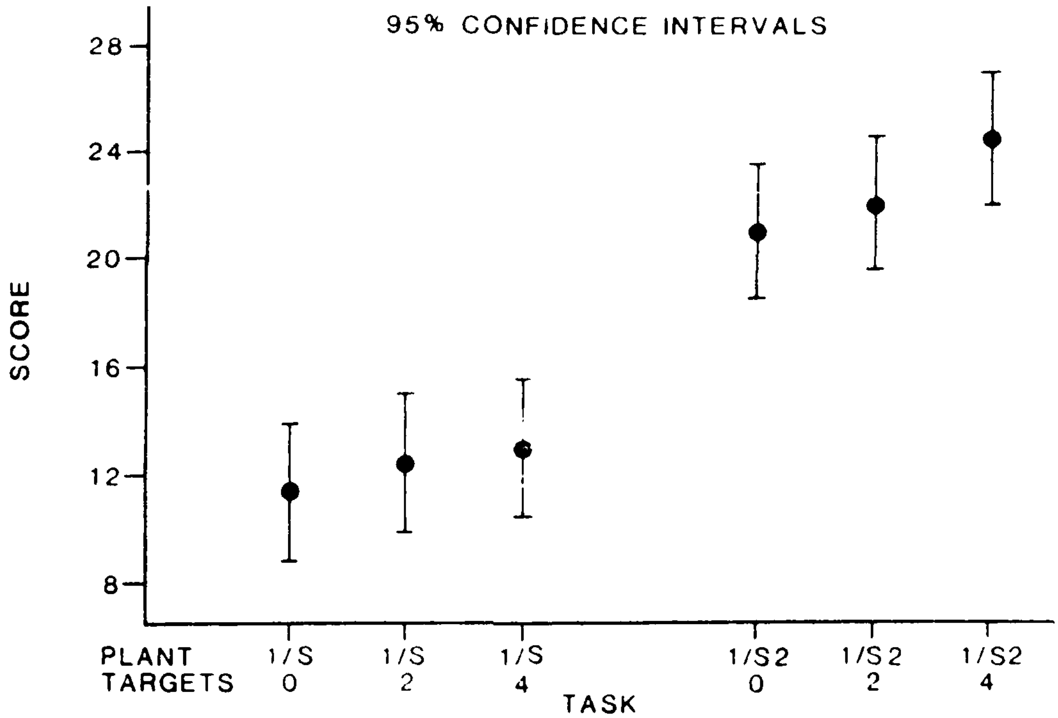


FIGURE 24a. PRIMARY TRACKING TASK ERROR SCORE VS. TASK AVERAGED ACROSS NOISE

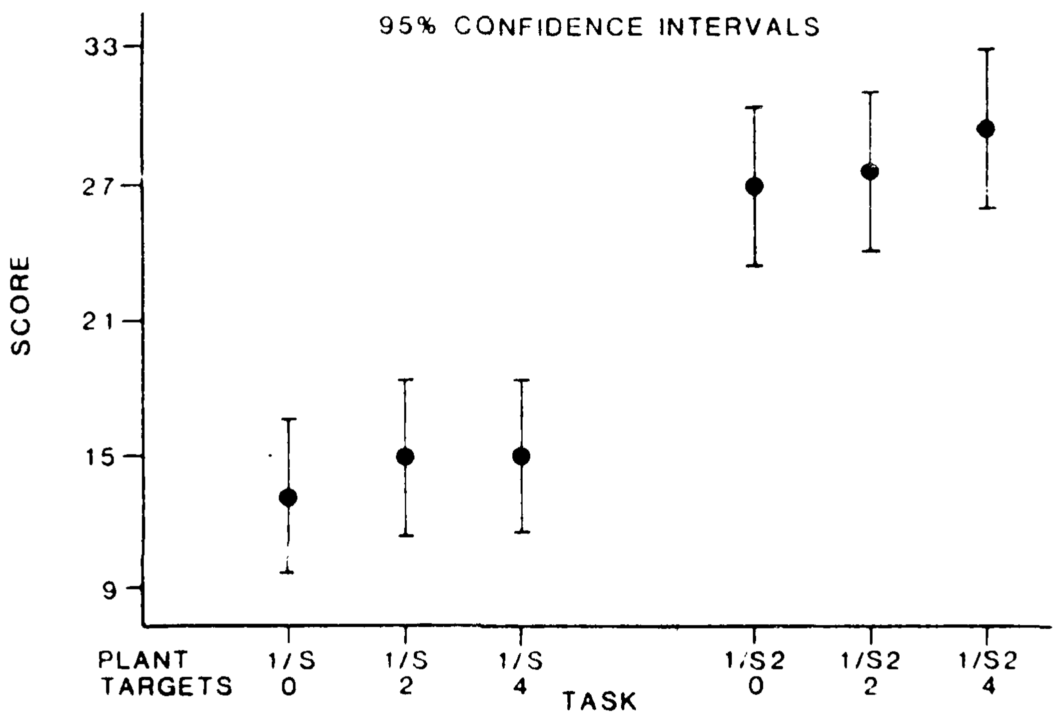


FIGURE 24b. PRIMARY TRACKING TASK ERROR SCORE VS. TASK AVERAGED ACROSS ACCELERATION

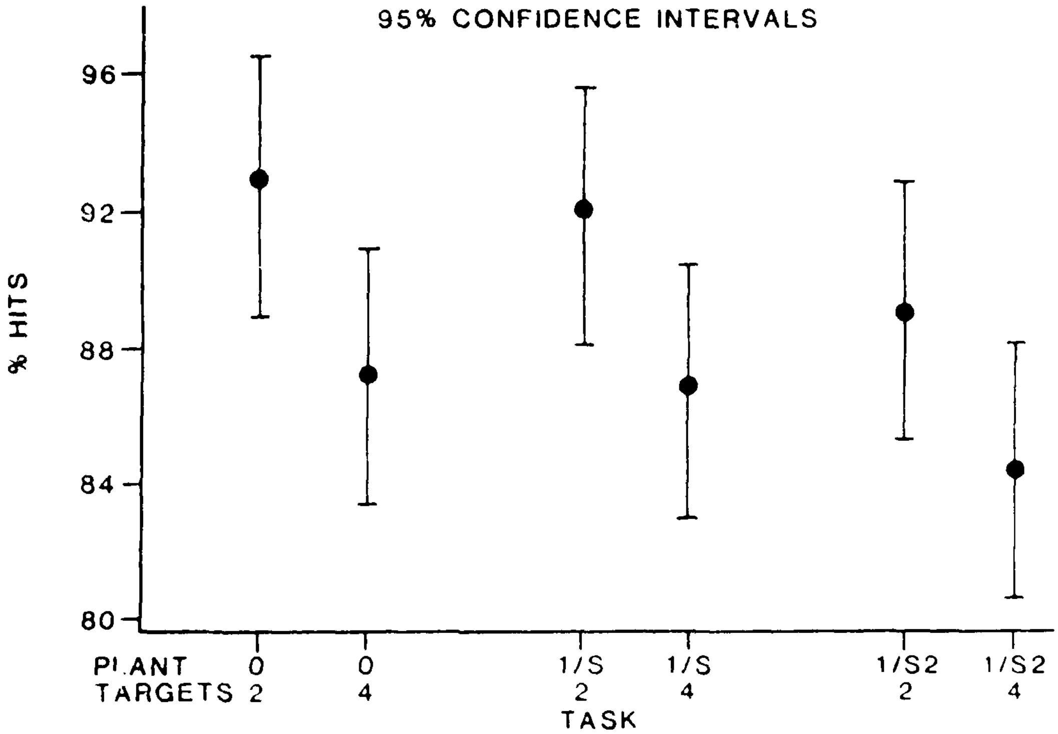


FIGURE 25a. SECONDARY TASK PERFORMANCE VS. TASK AVERAGED ACROSS NOISE

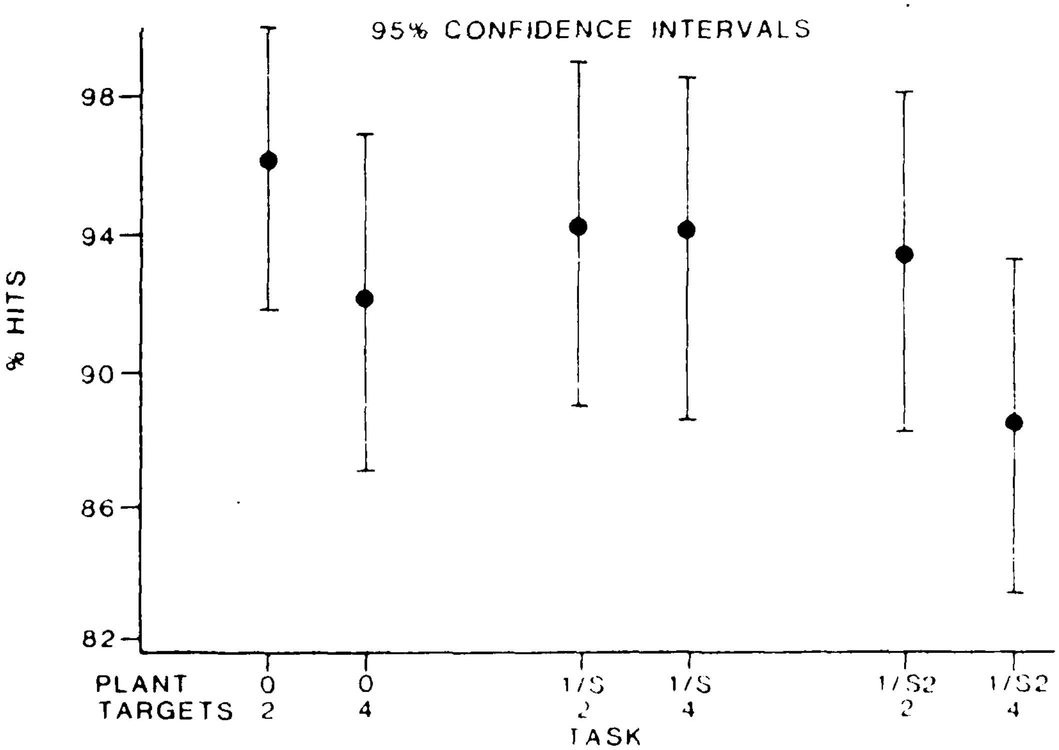


FIGURE 25b. SECONDARY TASK PERFORMANCE VS. TASK AVERAGED ACROSS ACCELERATION

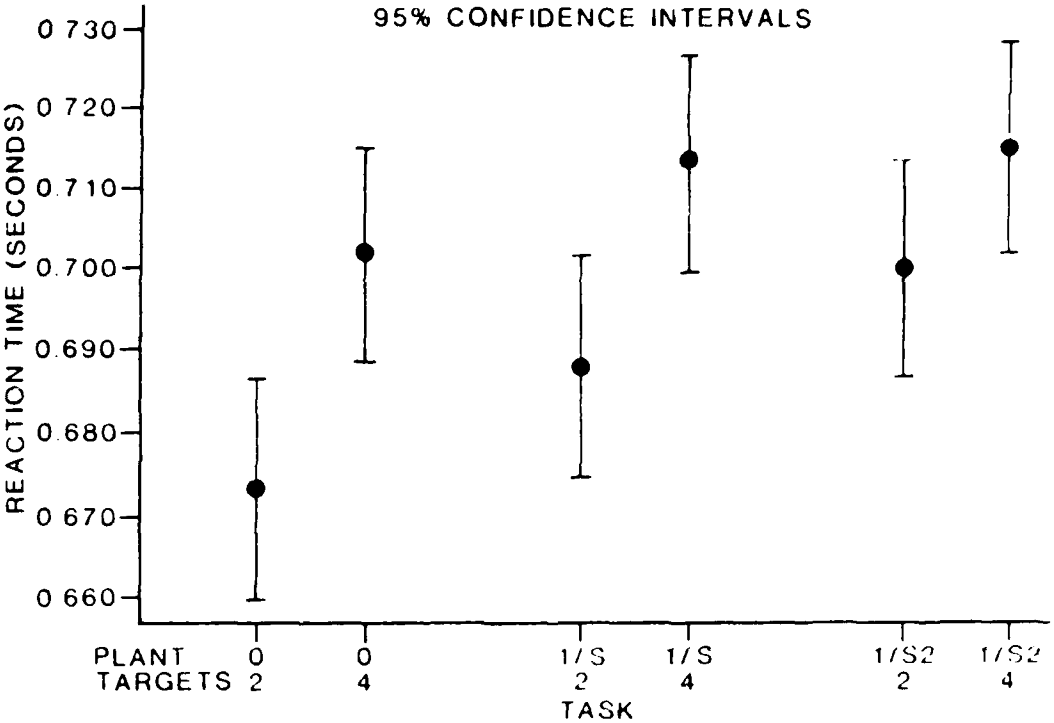


FIGURE 26a. SECONDARY TASK REACTION TIME VS. TASK AVERAGED ACROSS NOISE

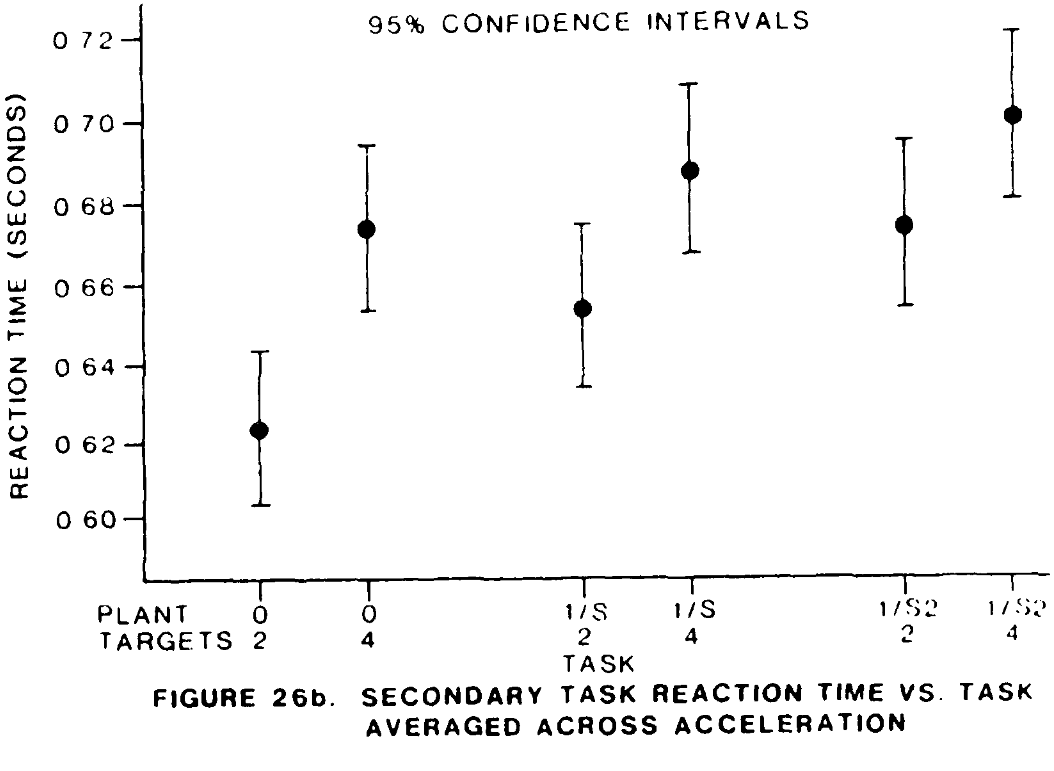


FIGURE 26b. SECONDARY TASK REACTION TIME VS. TASK AVERAGED ACROSS ACCELERATION

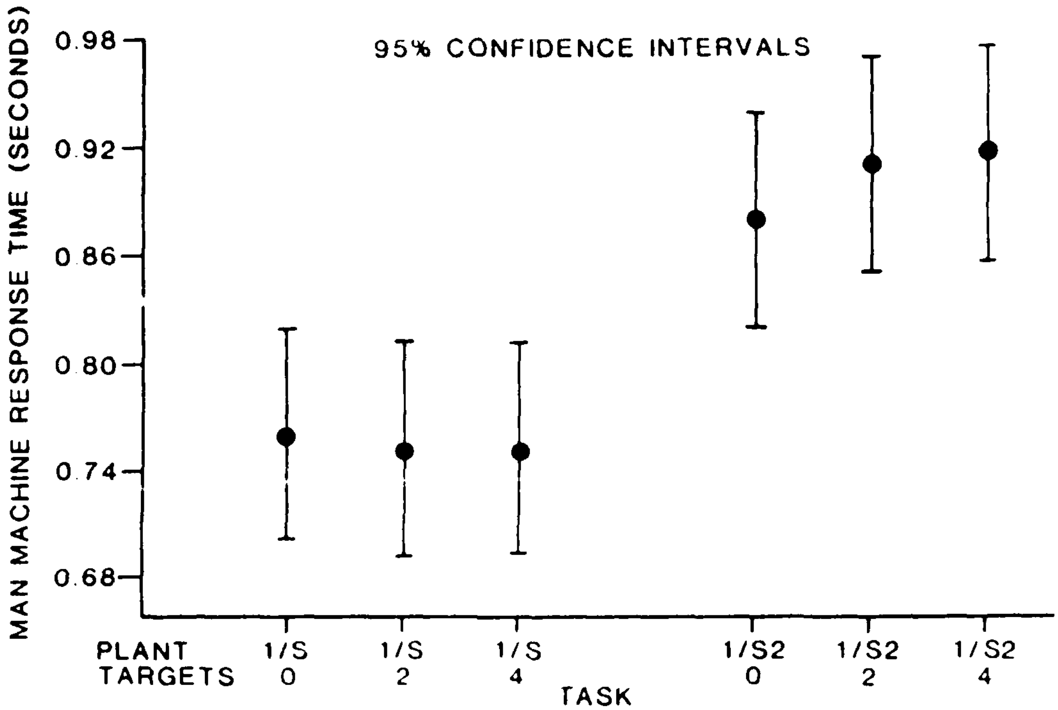


FIGURE 27a. MAN-MACHINE RESPONSE TIME VS. TASK AVERAGED ACROSS NOISE

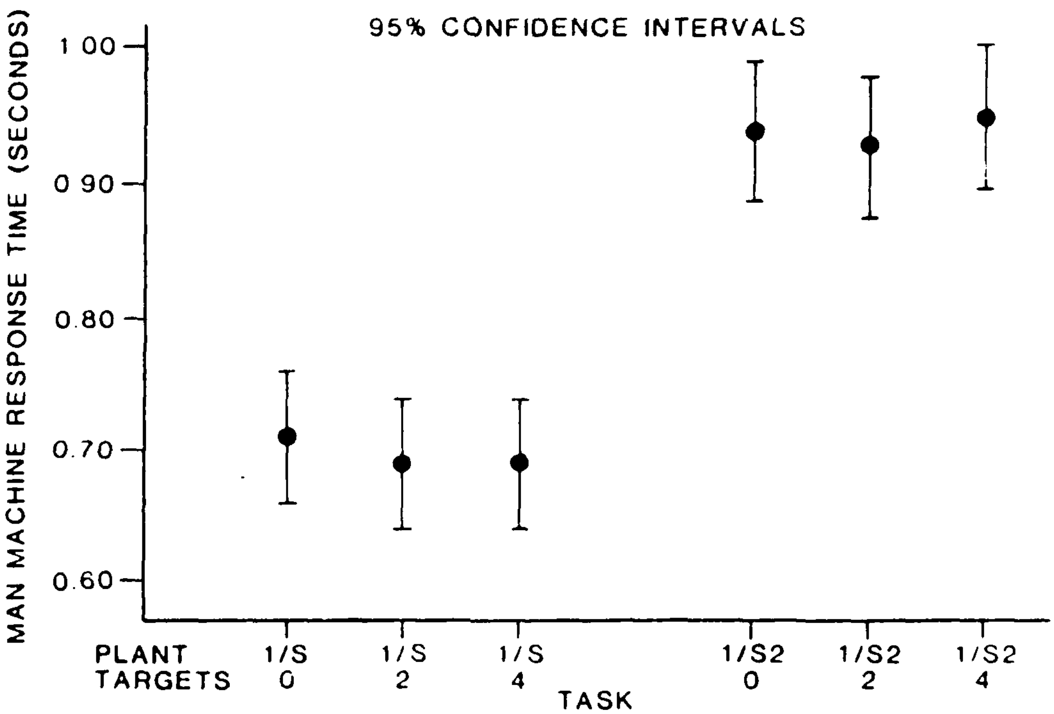


FIGURE 27b. MAN-MACHINE RESPONSE TIME VS. TASK AVERAGED ACROSS ACCELERATION

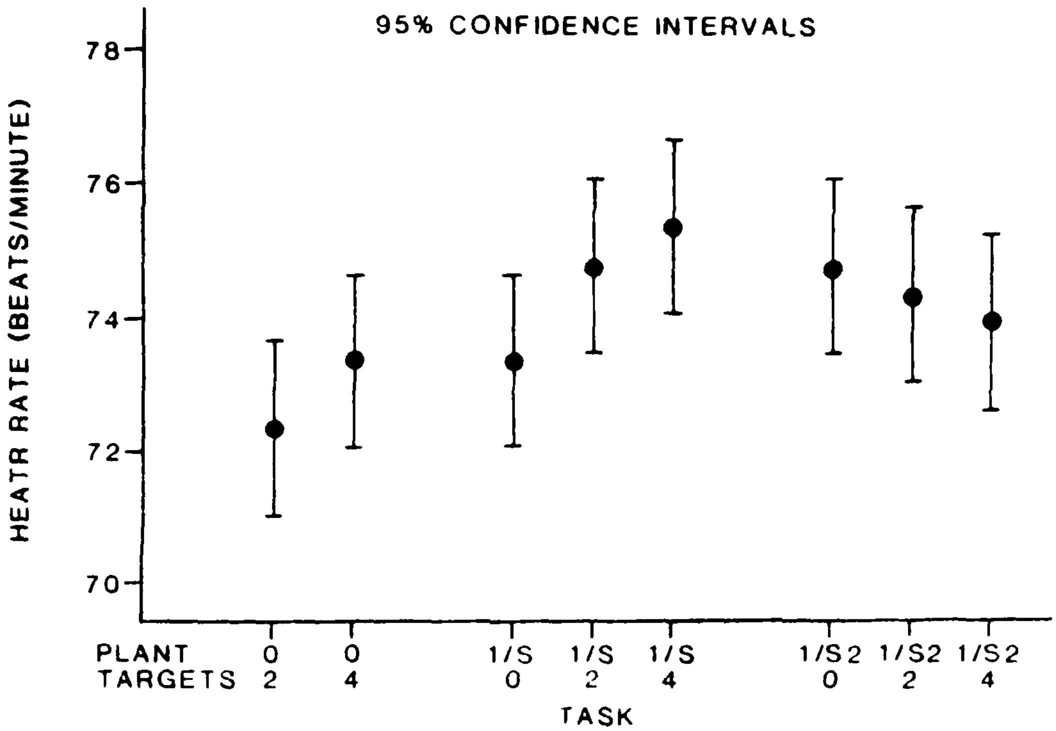


FIGURE 28a. HEART RATE VS. TASK AVERAGED ACROSS NOISE

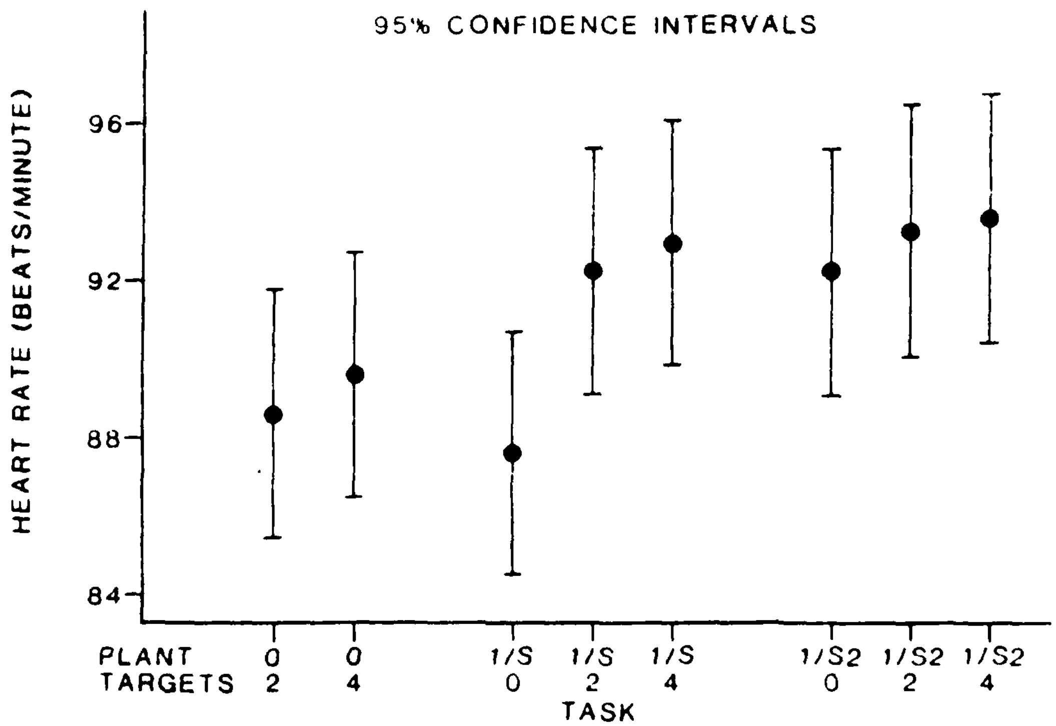


FIGURE 28b. HEART RATE VS. TASK AVERAGED ACROSS ACCELERATION

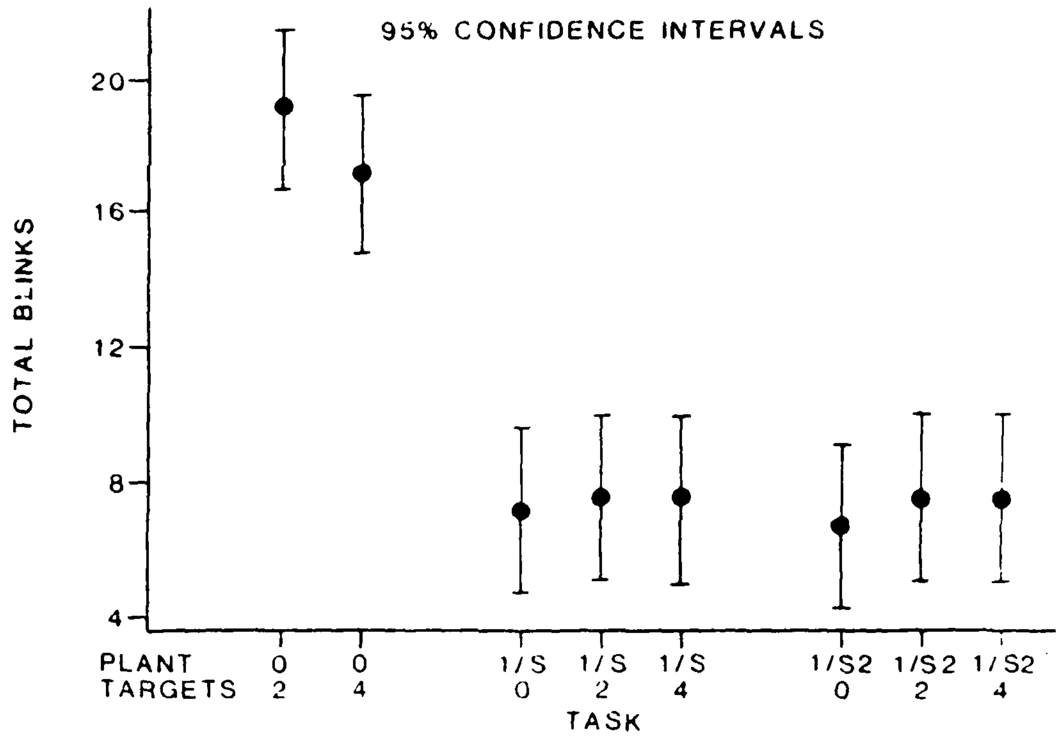


FIGURE 29a. TOTAL EYE BLINKS VS. TASK AVERAGED ACROSS NOISE

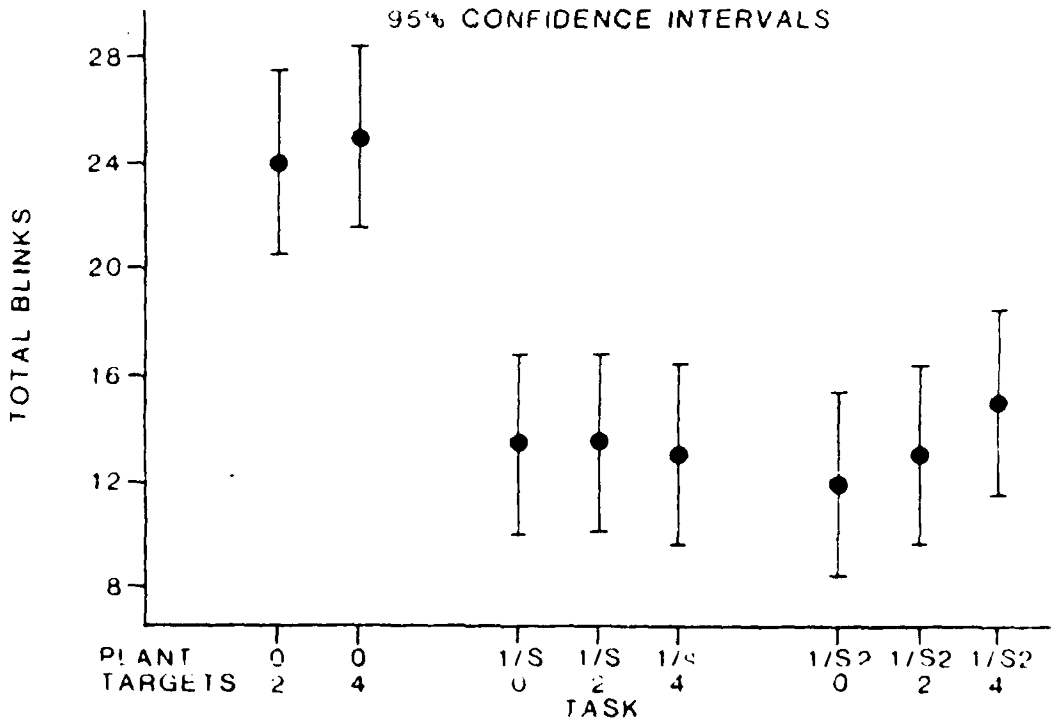


FIGURE 29b. TOTAL EYE BLINKS VS. TASK AVERAGED ACROSS ACCELERATION

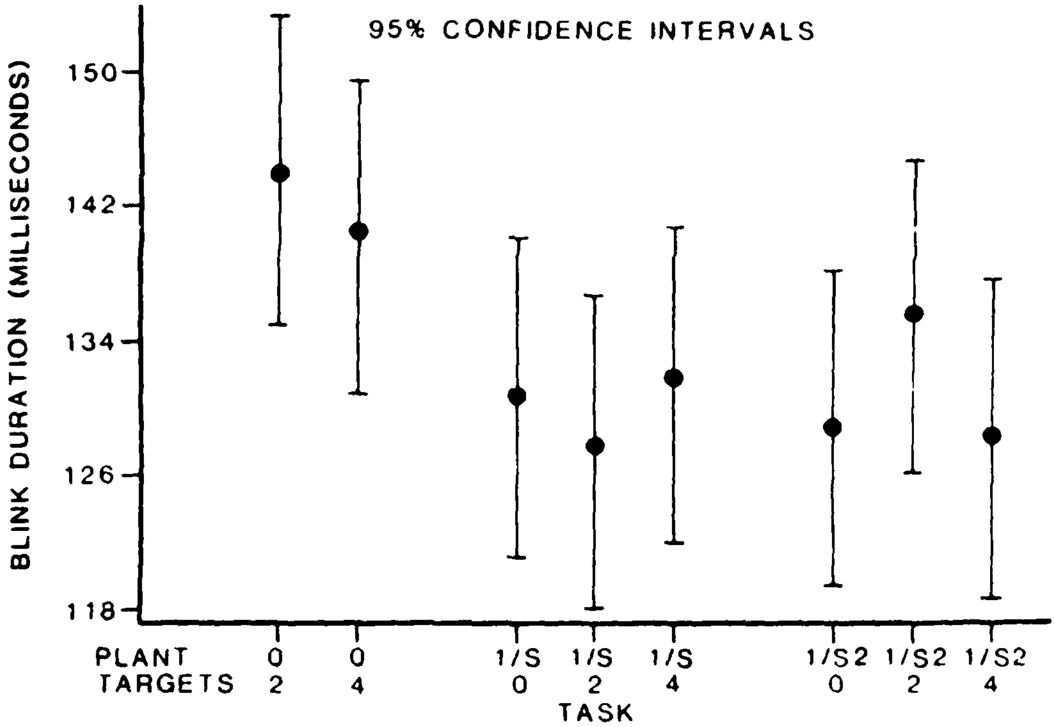


FIGURE 30a. EYE BLINK DURATION VS. TASK AVERAGED ACROSS NOISE

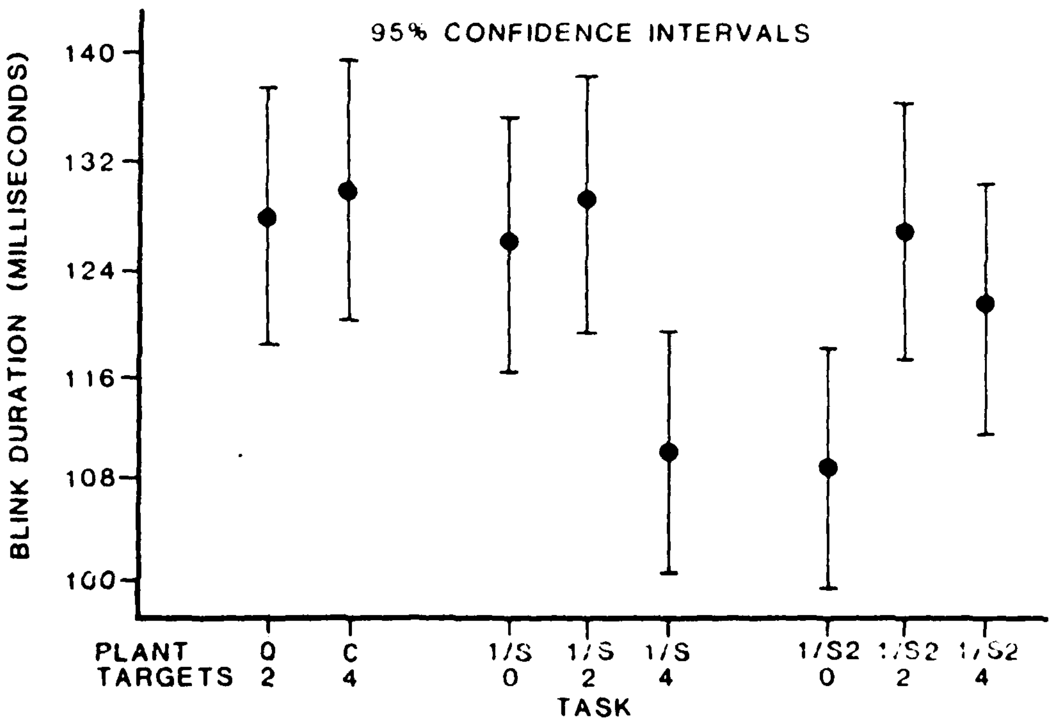


FIGURE 30b. EYE BLINK DURATION VS. TASK AVERAGED ACROSS ACCELERATION

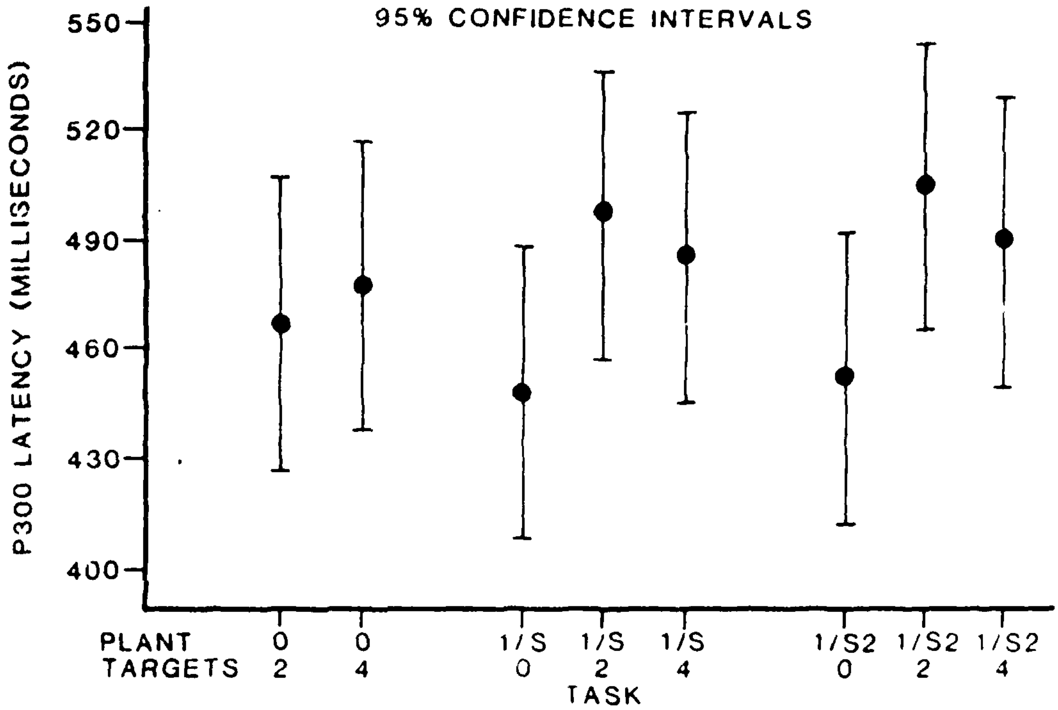


FIGURE 31a. P300 LATENCY VS. TASK AVERAGED ACROSS NOISE

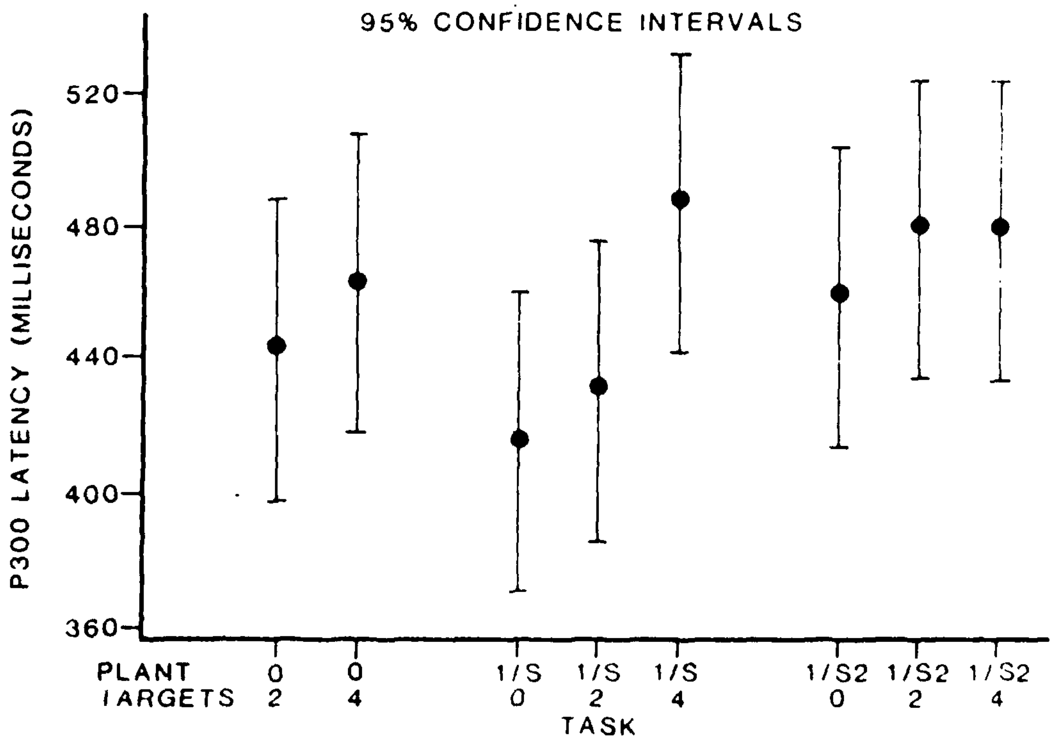


FIGURE 31b. P300 LATENCY VS. TASK AVERAGED ACROSS ACCELERATION

FIGURE 31C

P300 AND REACTION TIME DURING NOISE EXPOSURES vs. ITEMS IN MEMORY

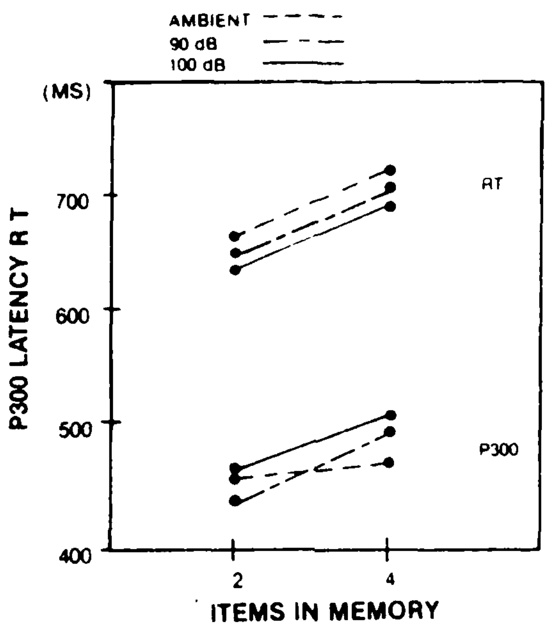
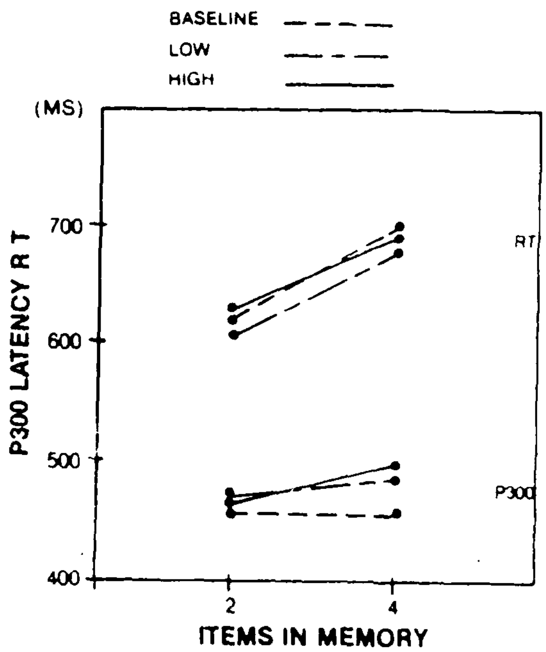


FIGURE 31D

P300 AND REACTION TIME DURING ACCELERATION EXPOSURES vs ITEMS IN MEMORY



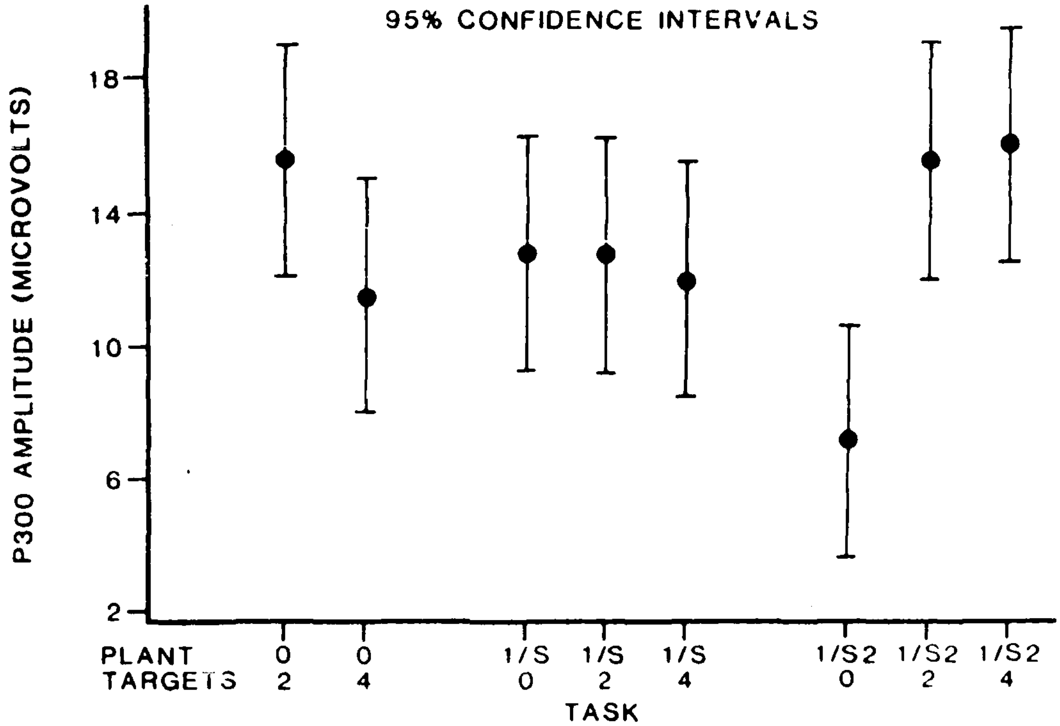


FIGURE 32a. P300 AMPLITUDE VS. TASK AVERAGED ACROSS NOISE

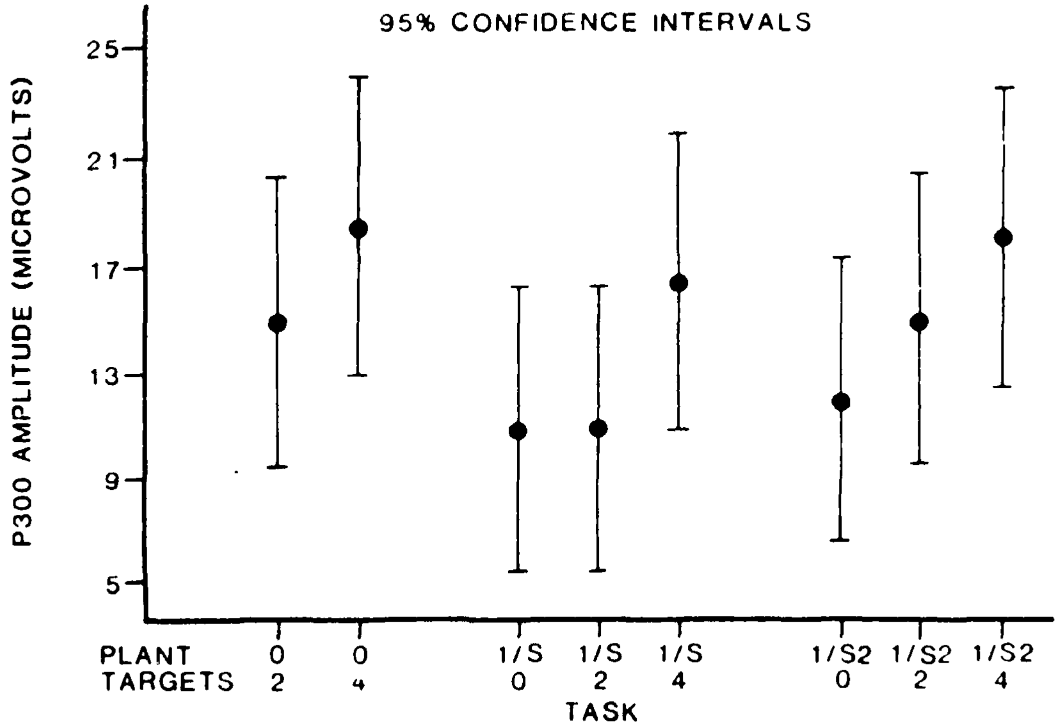


FIGURE 32b. P300 AMPLITUDE VS. TASK AVERAGED ACROSS ACCELERATION

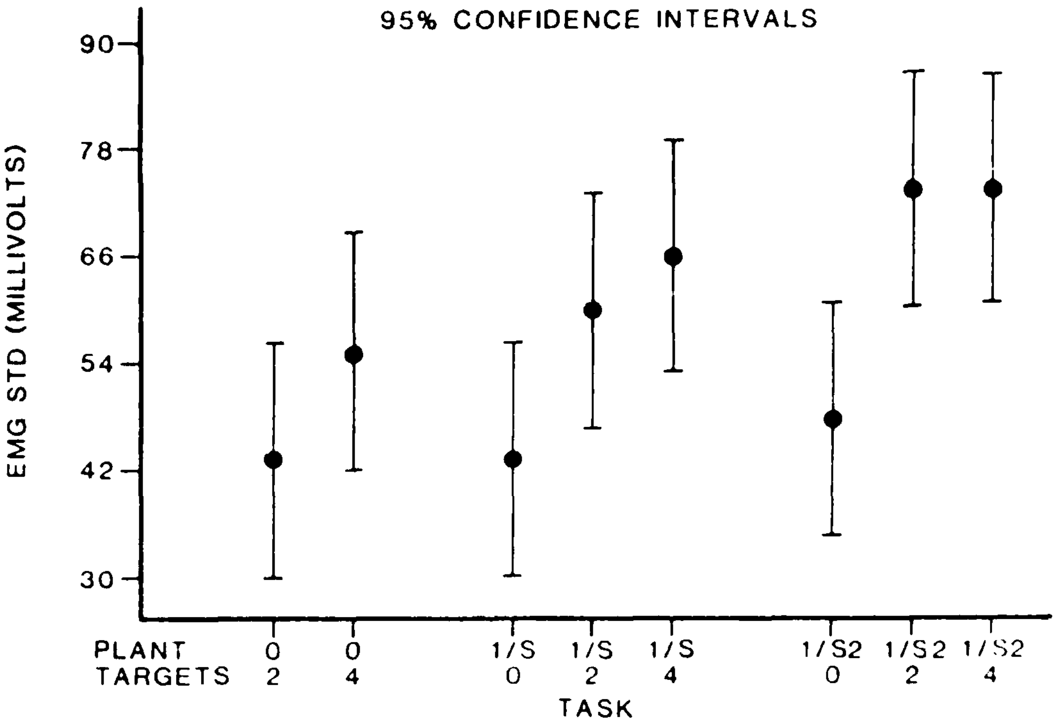


FIGURE 33a. EMG STANDARD DEVIATION (STD) VS. TASK AVERAGED ACROSS NOISE

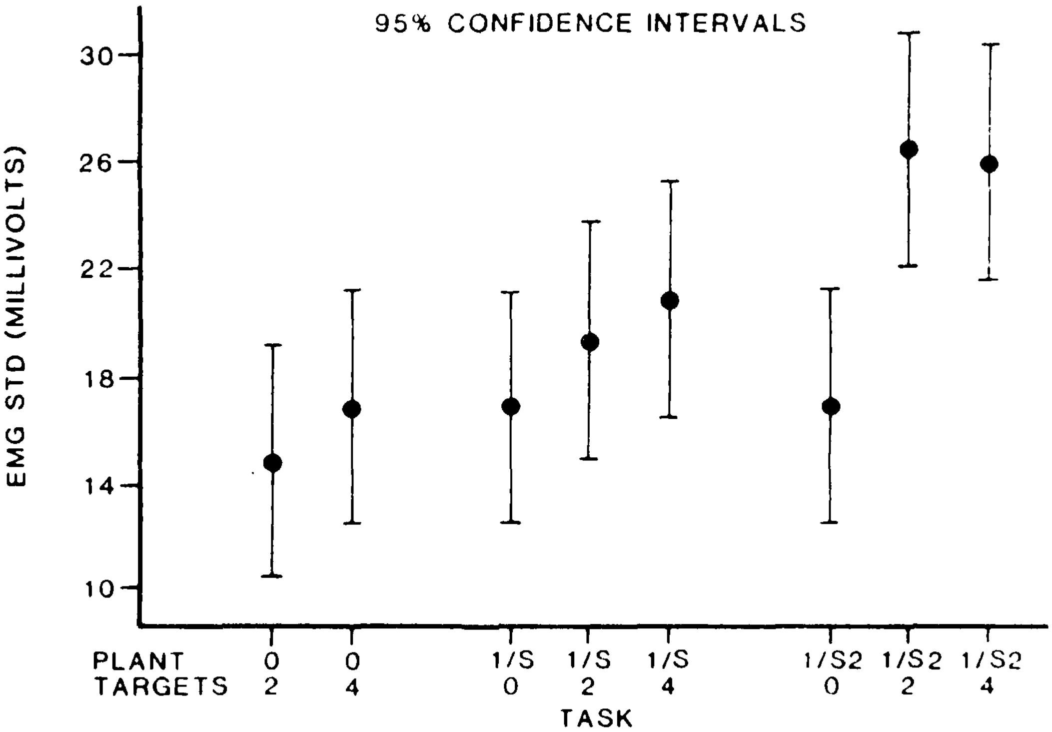


FIGURE 33b. EMG STANDARD DEVIATION (STD) VS. TASK AVERAGED ACROSS ACCELERATION

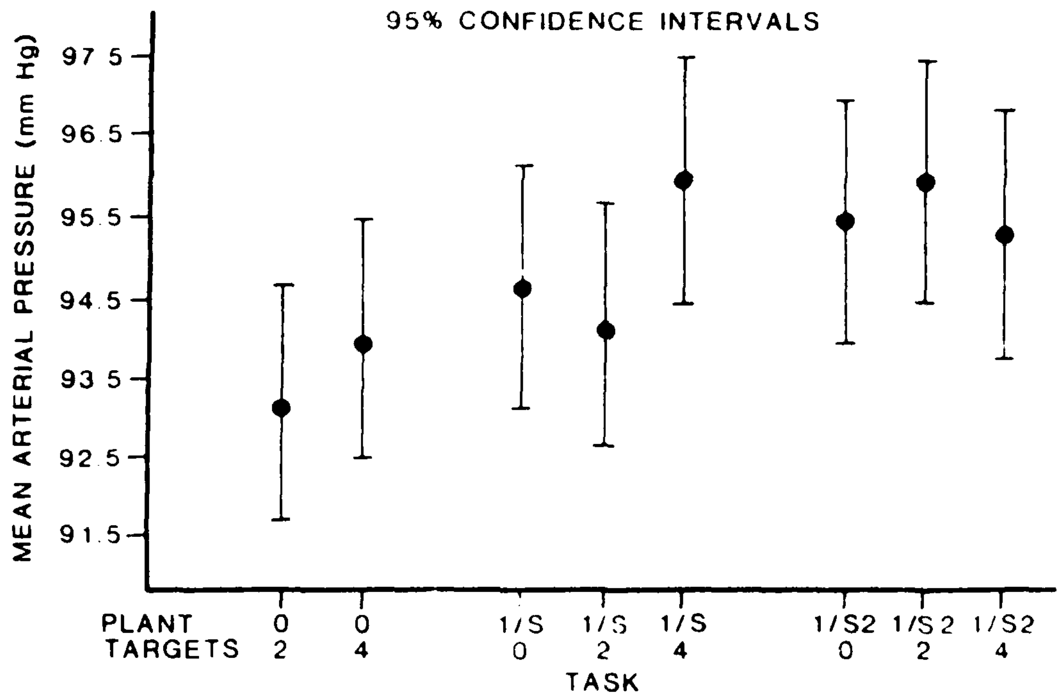


FIGURE 34. MEAN ARTERIAL BLOOD PRESSURE VS. TASK AVERAGED ACROSS NOISE

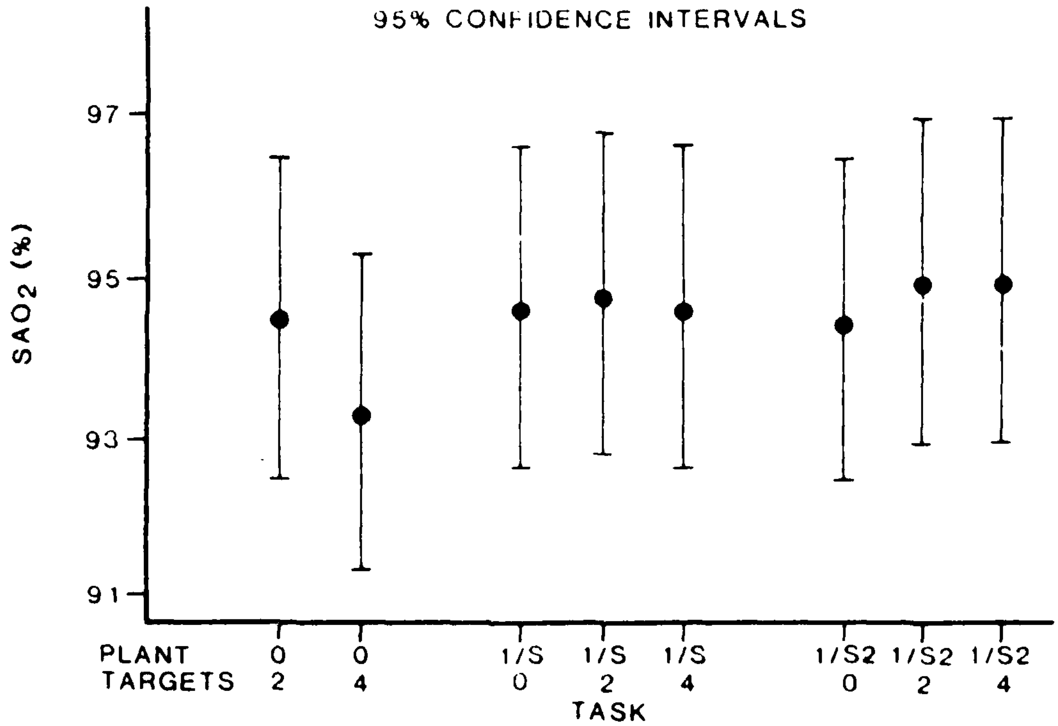


FIGURE 35. PERCENT ARTERIAL OXYGEN SATURATION VS. TASK AVERAGED ACROSS ACCELERATION

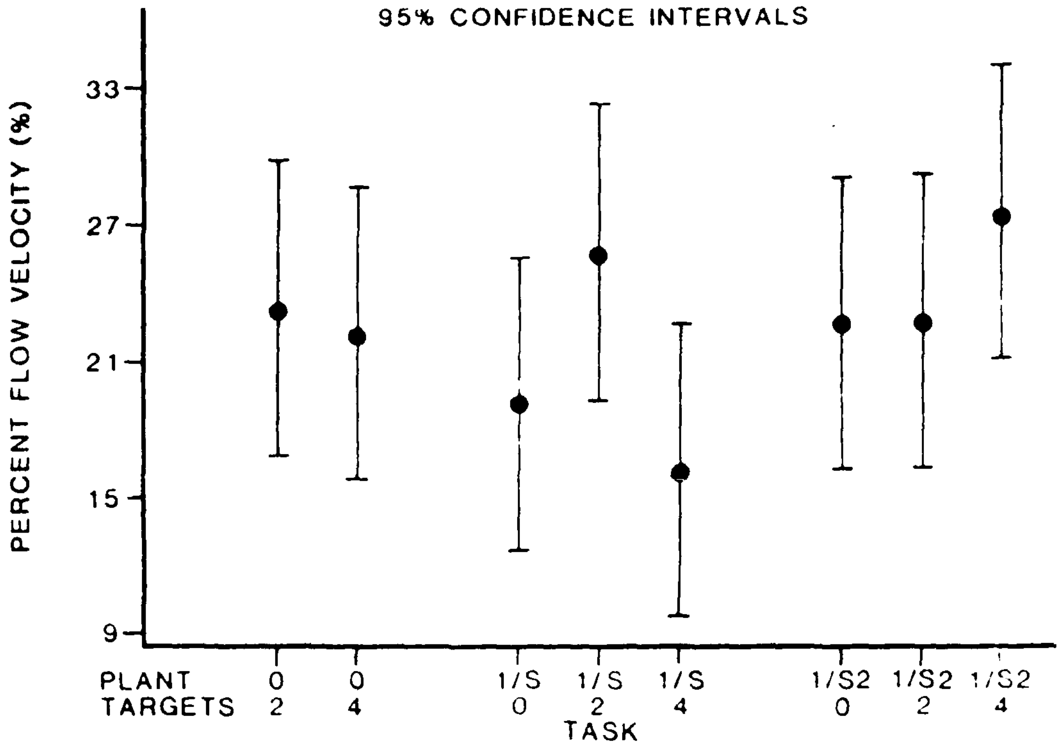


FIGURE 36. PERCENT TEMPORAL ARTERY FLOW VELOCITY VS. TASK AVERAGED ACROSS ACCELERATION

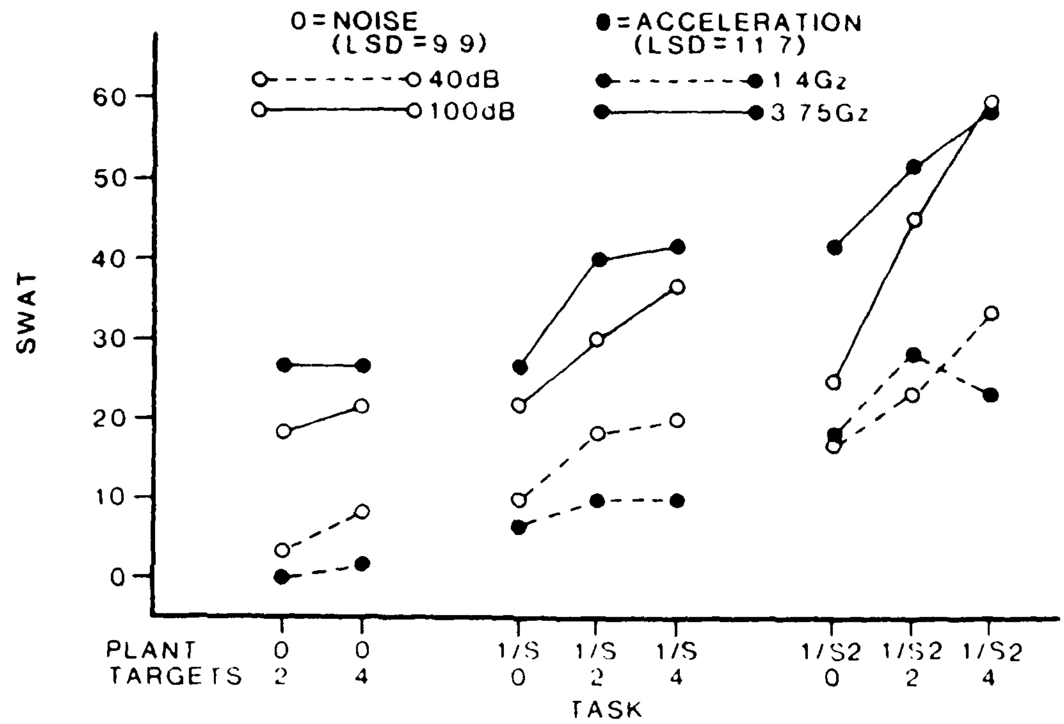


FIGURE 37. SWAT VS. TASK COMBINATION AND STRESSOR

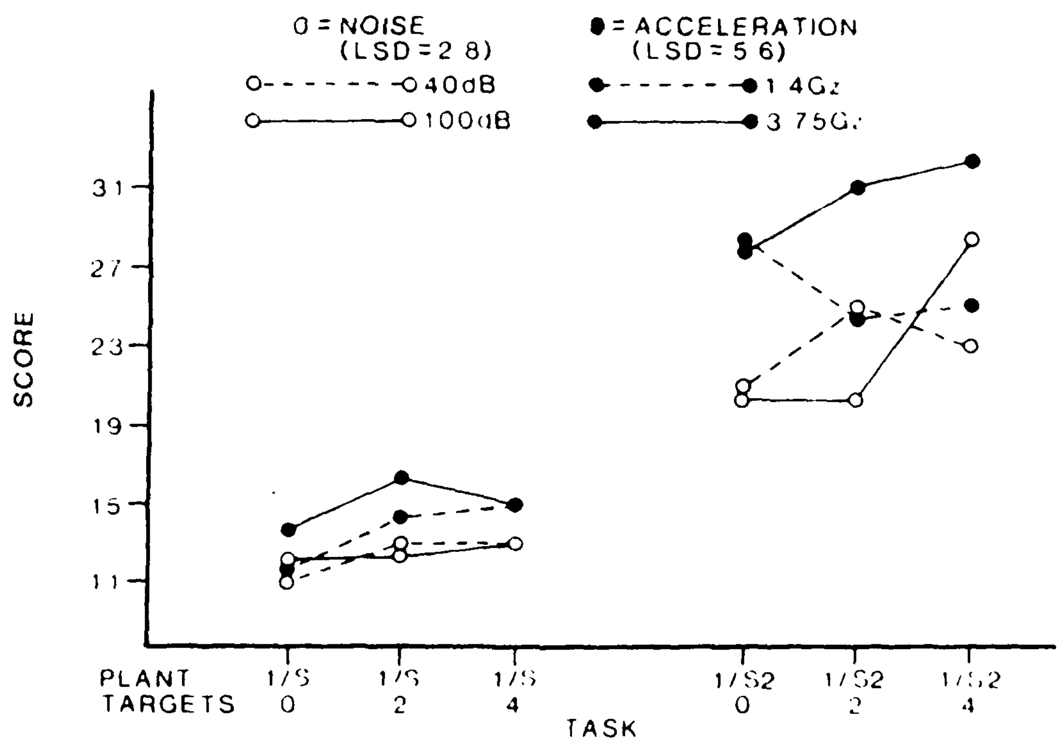


FIGURE 38. PRIMARY TRACKING TASK ERROR SCORE VS TASK COMBINATION AND STRESSOR

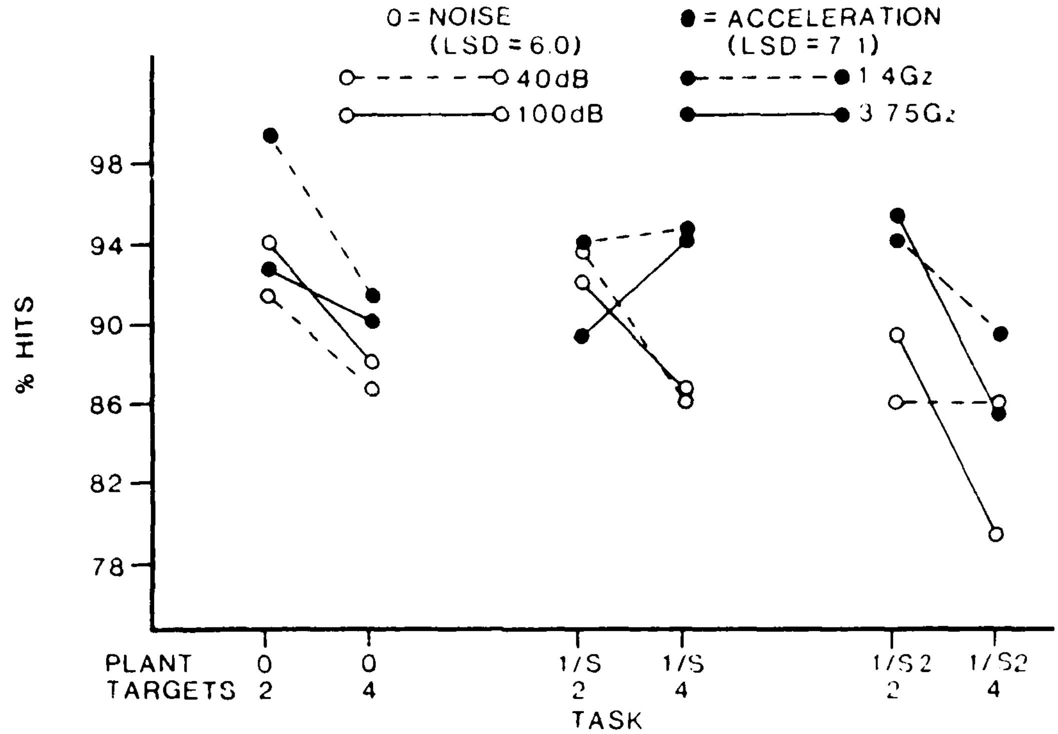


FIGURE 39. SECONDARY TASK PERFORMANCE VS. TASK COMBINATION AND STRESSOR

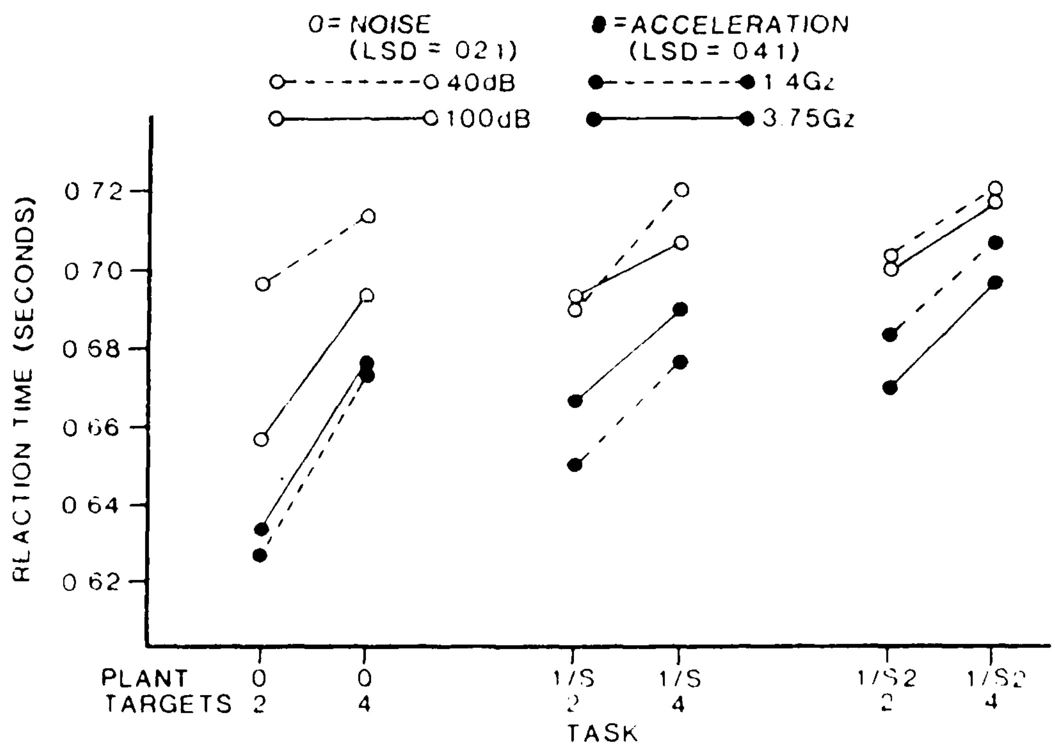


FIGURE 40. SECONDARY TASK REACTION TIME VS. TASK COMBINATION AND STRESSOR

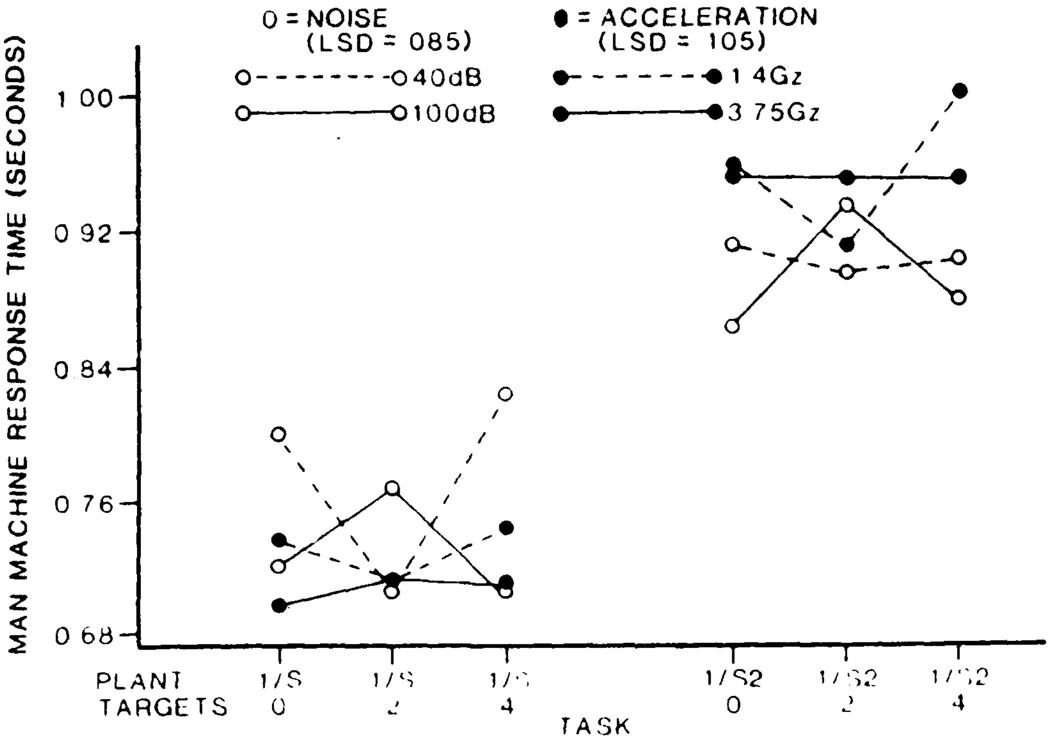


FIGURE 4 1. MAN-MACHINE RESPONSE TIME VS. TASK COMBINATION AND STRESSOR

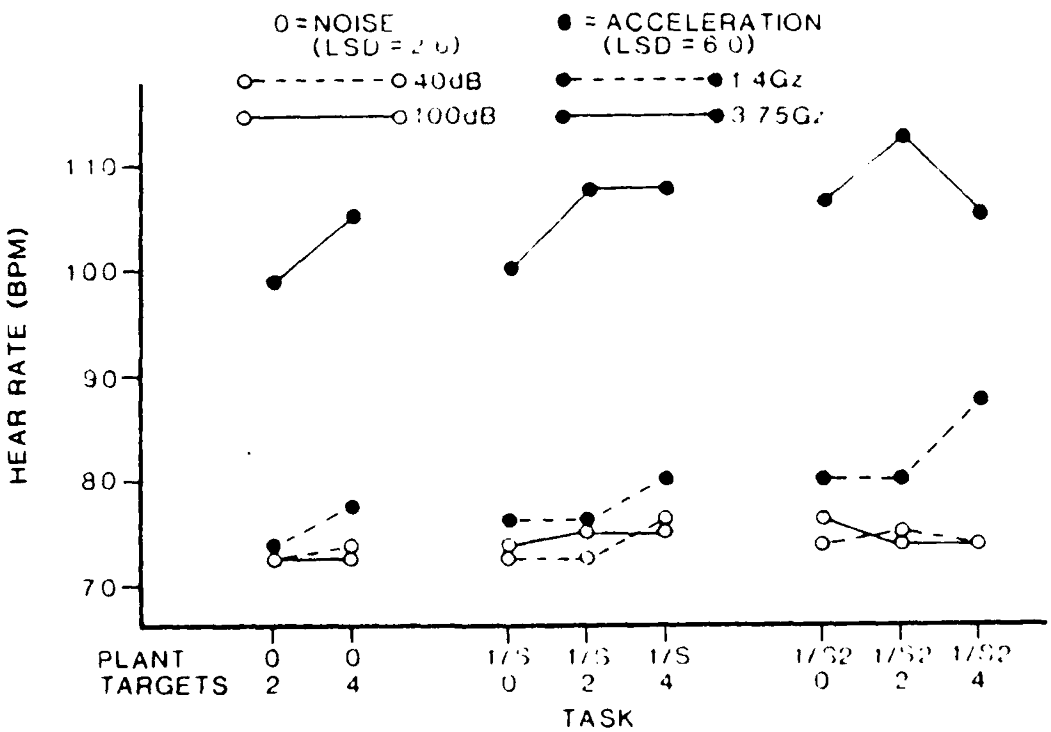


FIGURE 4 2. HEART RATE VS TASK COMBINATION AND STRESSOR

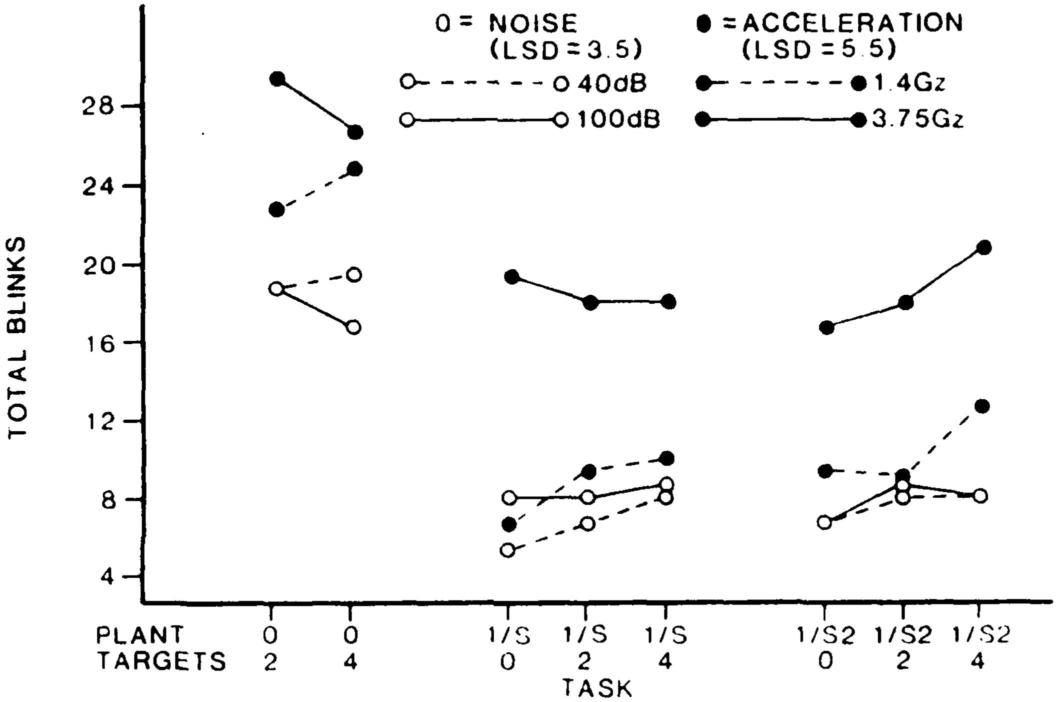


FIGURE 43. TOTAL EYE BLINKS VS. TASK COMBINATION AND STRESSOR

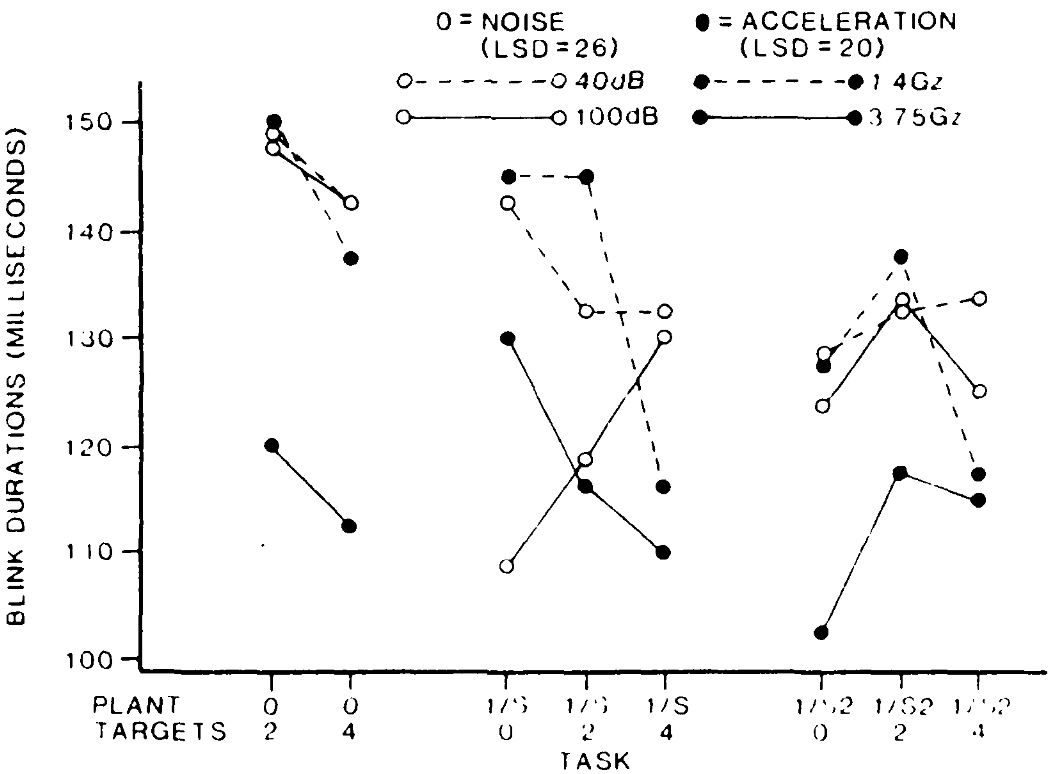


FIGURE 44. EYE BLINK DURATION VS. TASK COMBINATION AND STRESSOR

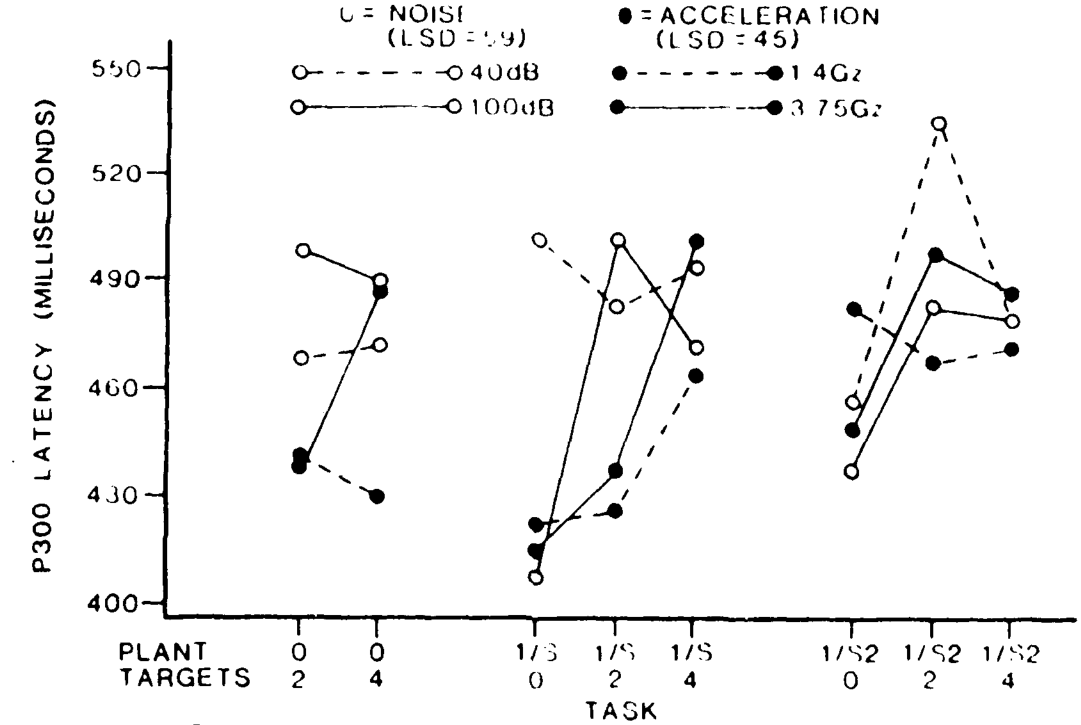


FIGURE 45. P300 LATENCY VS. TASK COMBINATION AND STRESSOR

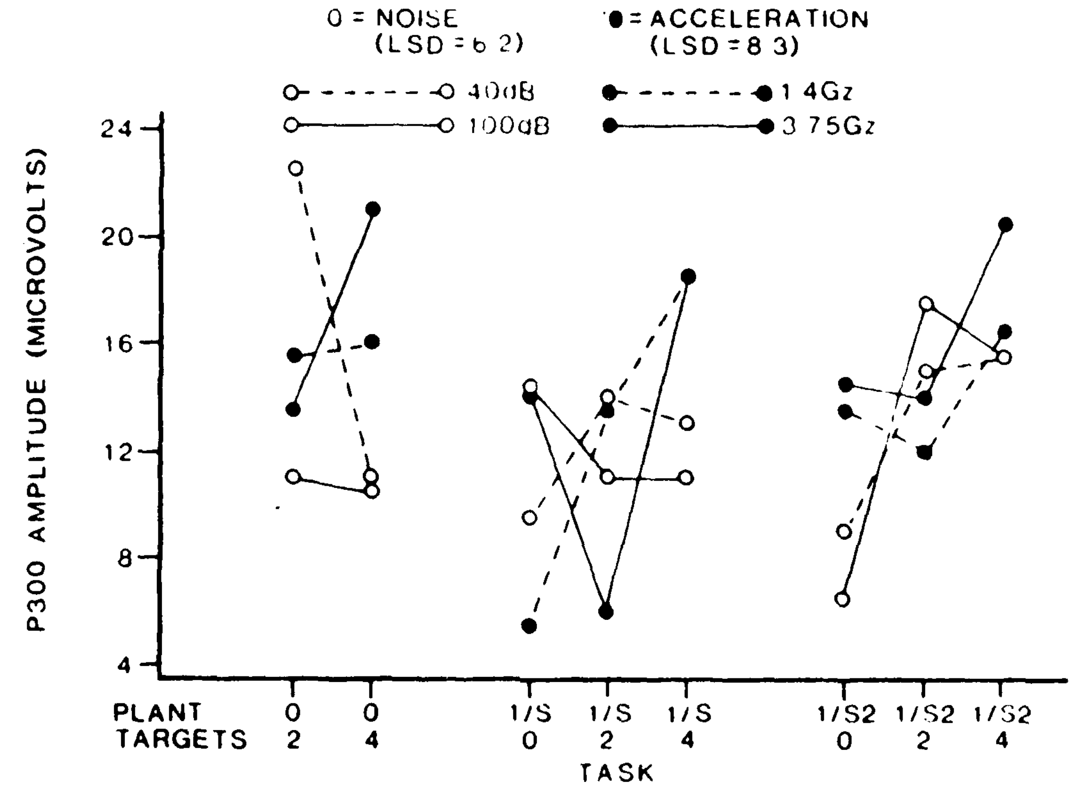


FIGURE 46. P300 AMPLITUDE VS. TASK COMBINATION AND STRESSOR

FIGURE 47. +4.5 G_Z ACCELERATION EXPOSURE

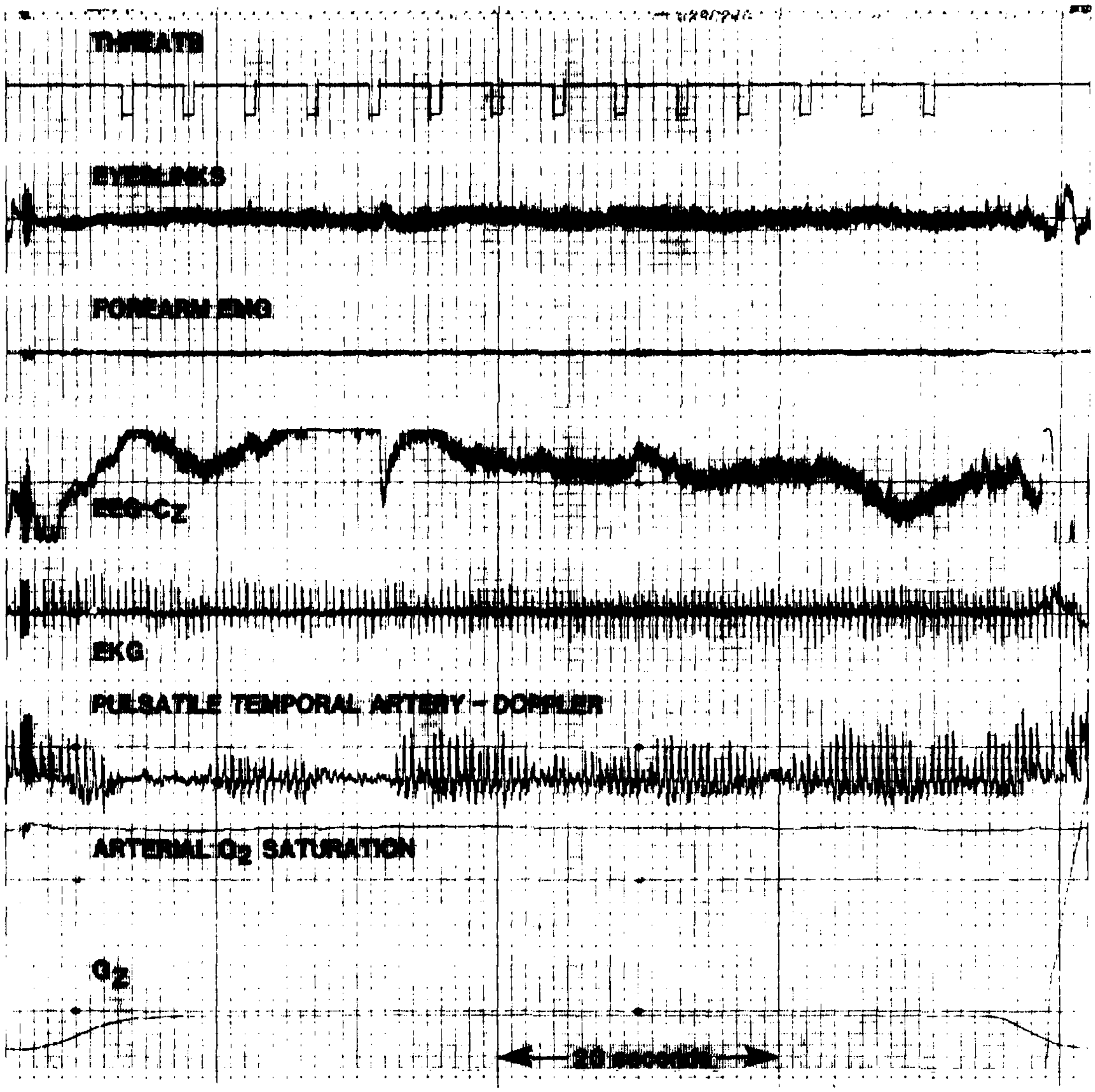


FIGURE 48

MEAN SWAT COMPONENT RATINGS vs NOISE STRESS

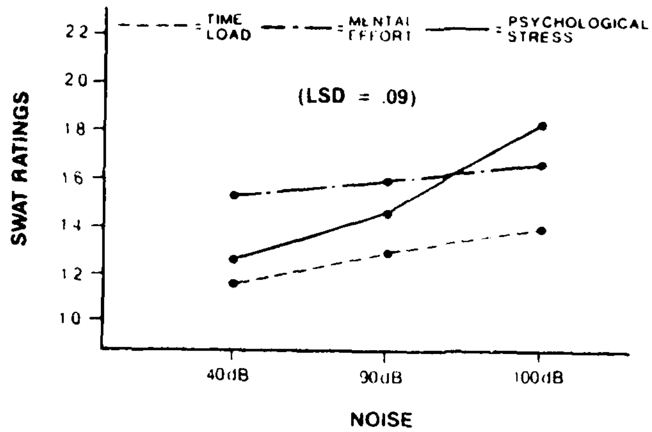


FIGURE 49

MEAN SWAT COMPONENT RATINGS vs ACCELERATION STRESS

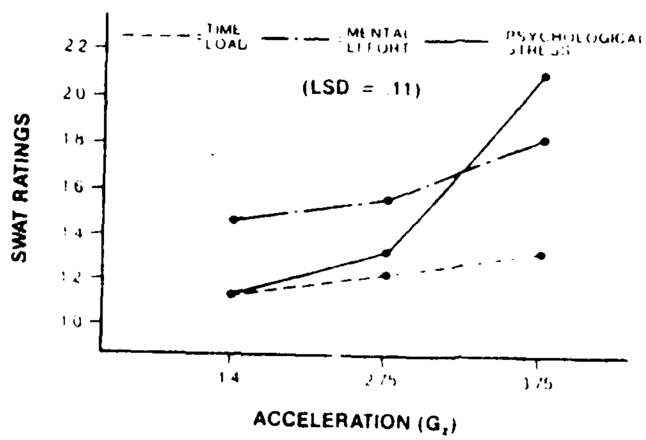


FIGURE 50

MEAN SWAT COMPONENT RATINGS vs TASK AVERAGED ACROSS NOISE

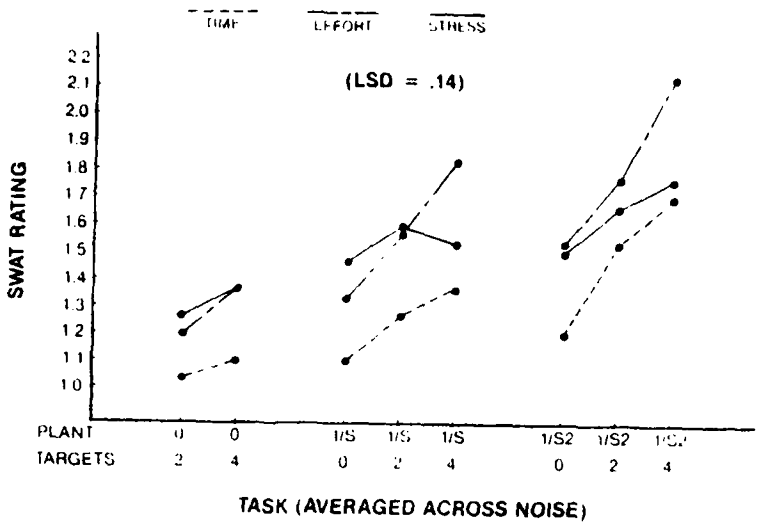


FIGURE 51

MEAN SWAT COMPONENT RATINGS vs TASK AVERAGED ACROSS ACCELERATION

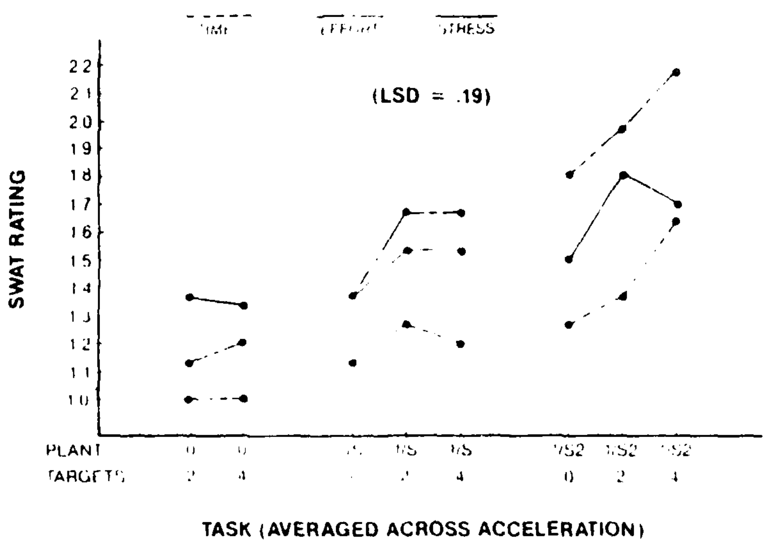


FIGURE 52

SWAT vs STRESSOR

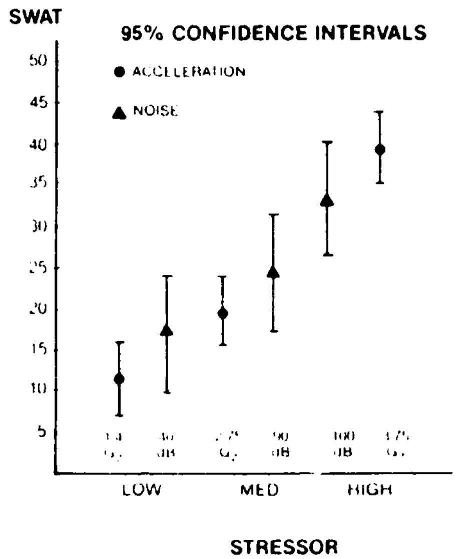


FIGURE 53

SWAT vs TASK DIFFULTY AVERAGED ACROSS STRESSOR

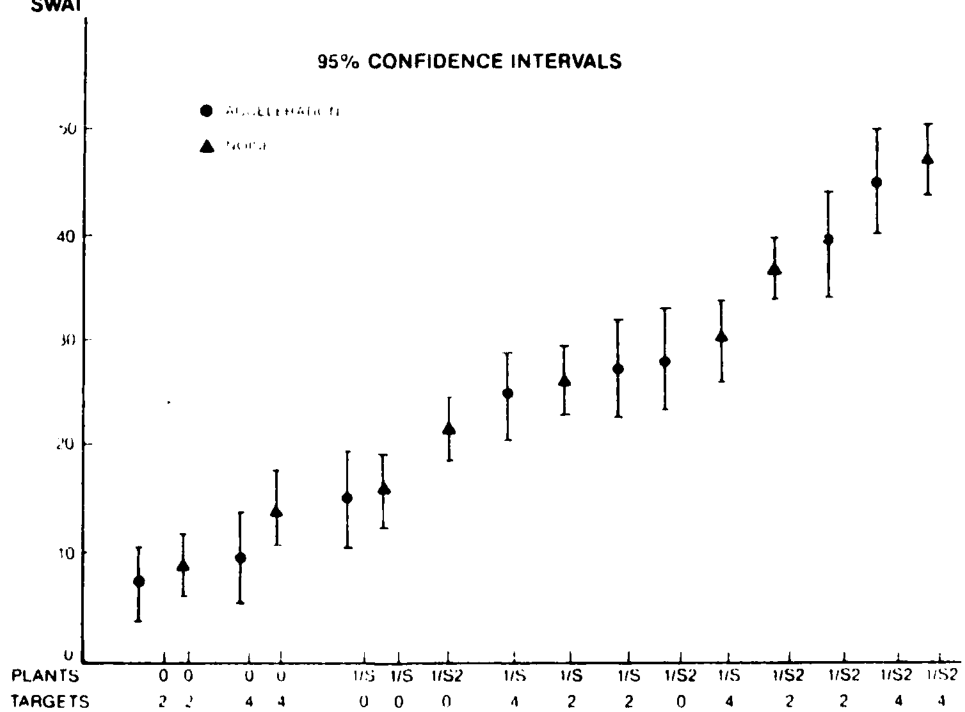


FIGURE 54

ERROR SCORE vs STRESSOR

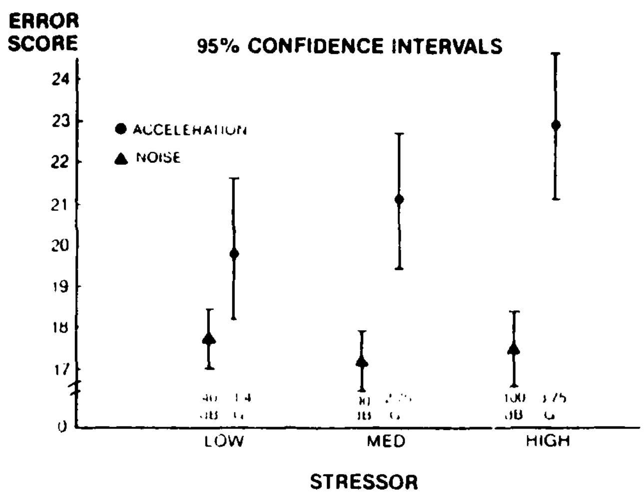


FIGURE 55

TRACKING ERROR SCORE vs TASK DIFFICULTY AVERAGED ACROSS STRESSOR

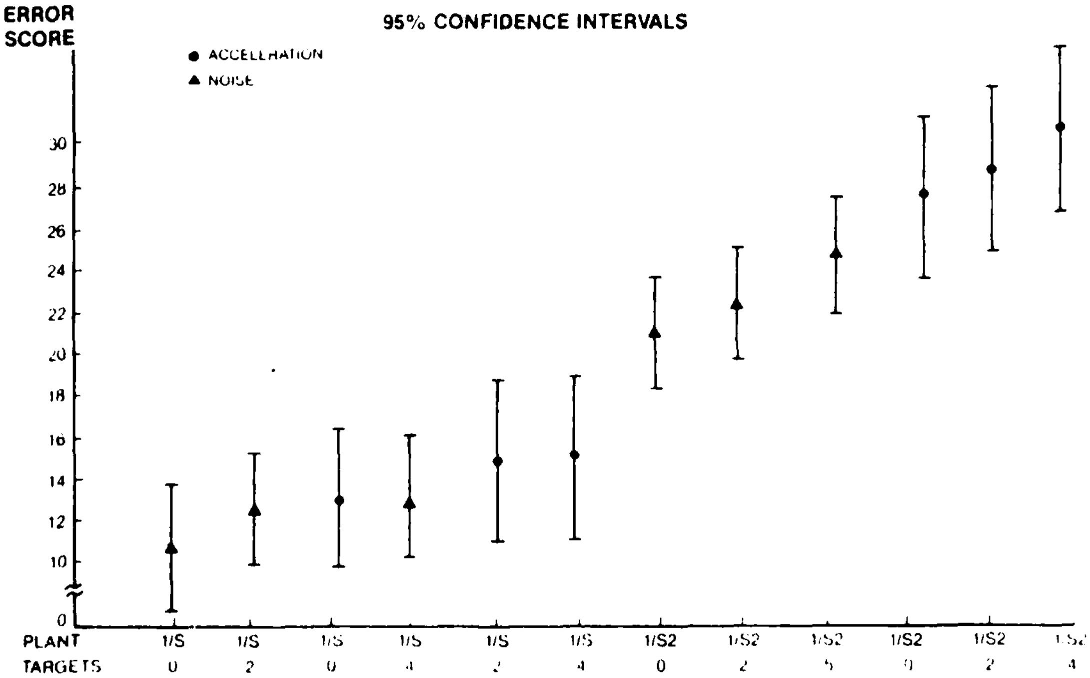


FIGURE 56

HEART RATE vs STRESSOR

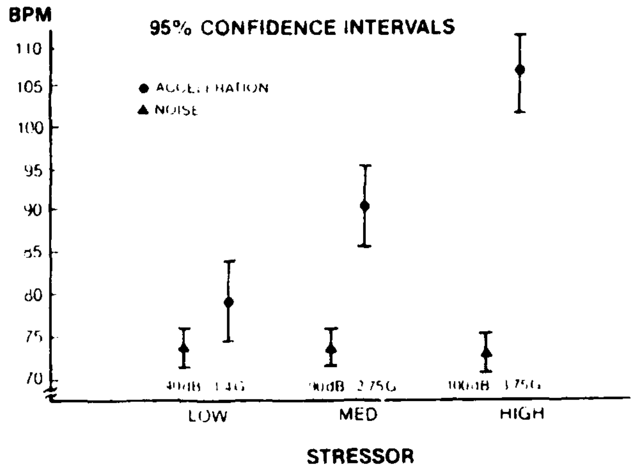


FIGURE 57

HEART RATE vs TASK DIFFICULTY AVERAGED ACROSS STRESSOR

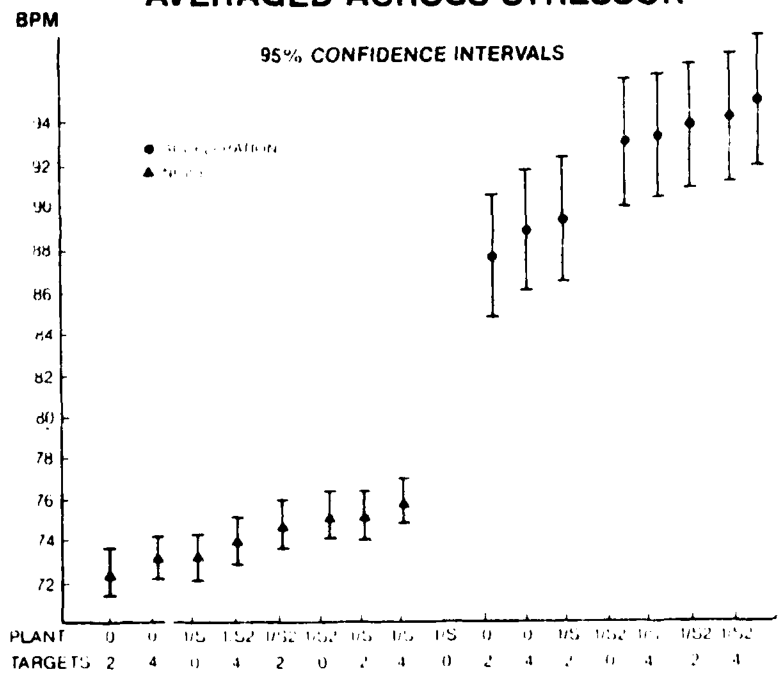


TABLE 1

EXPERIMENTAL DESIGN FOR NOISE PHASE

COMBINATION	PLANT	THREATS	NOISE (dB)
1	P2	0	A
2	—	4	90
3	P3	2	100
4	P2	0	90
5	P3	4	100
6	—	2	A
7	P2	4	90
8	P3	0	100
9	P2	2	90
10	—	4	A
11	P3	2	90
12	P2	4	100
13	P3	0	90
14	P2	4	A
15	—	2	100
16	P3	4	A
17	P2	2	100
18	P3	0	A
19	—	2	90
20	P2	0	100
21	P3	2	A
22	—	4	100
23	P2	2	A
24	P3	4	90

SUBJECT	DAY 1	DAY 2
1	1F	24R
2	17R	18F
3	8F	7R
4	4R	5F
5	21F	20R
6	13R	14F
7	3F	2R
8	19R	20F
9	11F	10R

LEGEND:
ab
a = COMBINATION
b = DIRECTION
F = FORWARD
R = REVERSE
A = AMBIENT

TABLE 2

EXPERIMENTAL DESIGN FOR ACCELERATION PHASE

GROUP	COMBINATION	PLANT	THREATS	ACCELERATION (G's)
	1	P3	4	LOW
	2	-	2	HIGH
	3	P2	0	BASELINE
	4	P3	2	LOW
	5	P2	4	HIGH
1	6	-	2	BASELINE
	7	P3	4	HIGH
	8	P2	0	LOW
	9	P3	2	BASELINE
	10	P2	0	HIGH
	11	-	4	LOW
	12	P2	2	BASELINE
	1	-	4	BASELINE
	2	P2	2	HIGH
	3	P3	0	LOW
	4	P2	4	BASELINE
	5	P3	0	HIGH
2	6		2	LOW
	7	P3	4	BASELINE
	8	P2	2	LOW
	9	—	4	HIGH
	10	P3	0	BASELINE
	11	P2	4	LOW
	12	P3	2	HIGH

SUBJECT	DAY 1	DAY 2
1	1-12F	2-8R
2	2-11R	1-3F
3	1-9R	2-6F
4	2-3F	1-11R
5	1-8F	2-3R
6	2-7R	1-11F
7	1-1R	2-7F
8	2-10F	1-4R

LEGEND:
a-bc
a = GROUP
b = COMBINATION
c = DIRECTION
F = FORWARD
R = REVERSE

TABLE 3

SUBJECT G TOLERANCES—EXPERIMENT II

SUBJECT	HIGH RELAXED TOLERANCE (G's)	LOWER EXPOSURE (HIGH-1.0G's)
830010	3.0	2.0
850013	3.5	2.5
860005	3.5	2.5
850001	3.5	2.5
830013	4.0	3.0
860016	4.0	3.0
840003	4.0	3.0
860002	4.5	3.5
MEAN	3.75	2.75

TABLE 4D. ANOVA TABLE, SWAT AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	8	10811	ERROR	12.06	.0001
TASK	7	23472	SUBJECT*TASK	26.66	.0001
NOISE	2	8530	SUBJECT*NOISE	17.15	.0001
SUBJECT*TASK	56	7044	ERROR	1.12	.2998
SUBJECT*NOISE	16	3980	ERROR	2.22	.0081
TASK*NOISE	14	1522	ERROR	0.97	.4887
ERROR	112	12555			
TOTAL	215	67913			

(I) MAIN EFFECTS FOR TASK (LSD = 6.1)

TASK	MEAN
0-2	9.5
0-4	14.7
1/S-0	16.0
1/S2-0	21.3
1/S-2	25.0
1/S-4	29.4
1/S2-2	33.5
1/S2-4	43.6

(II) MAIN EFFECTS FOR NOISE (LSD = 5.6)

NOISE	MEAN
A	16.6
90	23.8
100	32.0

(III)COMPARISON OF PLANT MEANS (LSD = 4.3)

PLANT	MEAN
0	12.1
1/S	27.2
1/S2	38.5

(IV)COMPARISON OF TARGETS MEANS (LSD = 4.3)

TARGETS	MEAN
0	18.7
2	29.2
4	36.5

TABLE 4E. ANOVA TABLE, SWAT AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	7	11521	ERROR	11.97	.0001
TASK	7	24060	SUBJECT*TASK	11.86	.0001
ACC	2	24207	SUBJECT*ACC	40.32	0001
SUBJECT*TASK	49	14201	ERROR	2.11	.0009
SUBJECT*ACC	14	4203	ERROR	2.18	.0135
TASK*ACC	14	2082	ERROR	1.08	.3836
ERROR	98	13475			
TOTAL	191	93749			

(I) MAIN EFFECTS FOR TASK (LSD = 9.9)

TASK	MEAN
0-2	8.7
0-4	9.6
1/S-0	15.4
1/S-4	24.6
1/S-2	25.0
1/S2-0	26.9
1/S2-2	36.8
1/S2-4	41.7

(II) MAIN EFFECTS FOR ACC (LSD = 6.6)

ACC	MEAN
BASE	12.5
LOW	19.3
HIGH	39.0

(III) COMPARISON OF PLANT MEANS (LSD = 7.0)

PLANT	MEAN
0	9.1
1/S	24.8
1/S2	39.2

(IV) COMPARISON OF TARGETS MEANS (LSD = 7.0)

TARGETS	MEAN
0	21.1
2	30.9
4	33.2

TABLE 5A. ANOVA TABLE, PRIMARY TRACKING TASK ERROR SCORE AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	8	1132	ERROR	16.10	.0001
TASK	5	4421	SUBJECT*TASK	19.63	.0001
NOISE	2	6	SUBJECT*NOISE	0.45	.6434
SUBJECT*TASK	40	1802	ERROR	5.12	.0001
SUBJECT*NOISE	16	103	ERROR	0.73	.7544
TASK*NOISE	10	308	ERROR	3.50	.0007
ERROR	79	694			
TOTAL	160	8404			

(I) MAIN EFFECTS FOR TASK (LSD = 3.7)

TASK	MEAN
1/S-0	11.6
1/S-2	12.4
1/S-4	13.2
1/S2-0	21.1
1/S2-2	22.2
1/S2-4	24.6

(II) MAIN EFFECTS FOR NOISE (LSD = 1.0)

NOISE	MEAN
90	17.3
100	17.5
A	17.8

(III) COMPARISON OF PLANT MEANS(LSD = 2.1)

PLANT	MEAN
1/S	12.4
1/S2	22.6

(IV) COMPARISON OF TARGETS MEANS(LSD = 2.6)

TARGETS	MEAN
0	16.4
2	17.3
4	18.9

TABLE 5B. ANOVA TABLE, PRIMARY TRACKING TASK ERROR SCORE AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	7	1657	ERROR	7.41	[illegible]
TASK	5	6886	SUBJECT*TASK	17.23	[illegible]
ACC	2	214	SUBJECT*ACC	5.48	.0175
SUBJECT*TASK	35	2797	ERROR	2.50	.0006
SUBJECT*ACC	14	273	ERROR	0.61	.8473
TASK*ACC	10	326	ERROR	1.02	.4340
ERROR	70	2236			
TOTAL	143	14389			

(I) MAIN EFFECTS FOR TASK (LSD [illegible])

TASK	MEAN
1/S-0	13.1
1/S-2	14.9
1/S-4	15.0
1/S2-0	27.0
1/S2-2	27.6
1/S2-4	29.5

(II) MAIN EFFECTS FOR ACC (LSD = 1.9)

ACC	MEAN
BASE	19.8
LOW	21.0
HIGH	22.8

(III) COMPARISON OF PLANT MEANS(LSD 3.0)

PLANT	MEAN
1/S	14.3
1/S2	28.0

(IV) COMPARISON OF TARGETS MEANS(LSD [illegible])

TARGETS	MEAN
0	20.1
2	21.2
4	22.3

TABLE 6A. ANOVA TABLE, SECONDARY TASK PERFORMANCE AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	8	4625	ERROR	14.23	.0001
TASK	5	1395	SUBJECT*TASK	2.79	.0296
NOISE	2	62	SUBJECT*NOISE	0.93	.4139
SUBJECT*TASK	40	3998	ERROR	2.46	.0003
SUBJECT*NOISE	16	534	ERROR	0.82	.6578
TASK*NOISE	10	525	ERROR	1.29	.2486
ERROR	80	3249			
TOTAL	161	14388			

(I) MAIN EFFECTS FOR TASK (LSD = 5.5)

TASK	MEAN (%)
1/S2-4	84.3
1/S-4	86.9
0-4	87.3
1/S2-2	89.2
1/S-2	91.9
0-2	92.7

(II) MAIN EFFECTS FOR NOISE (LSD = 2.4)

NOISE	MEAN (%)
100	88.2
A	88.3
90	89.6

(III) COMPARISON OF PLANT MEANS(LSD = 3.9)

PLANT	MEAN (%)
1/S2	86.7
1/S	89.4
0	90.0

(IV) COMPARISON OF TARGETS MEANS(LSD = 3.2)

TARGETS	MEAN (%)
4	86.2
2	91.3

TABLE 6B. ANOVA TABLE, SECONDARY TASK PERFORMANCE AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	7	685	ERROR	1.91	.0811
TASK	5	823	SUBJECT*TASK	1.16	.3489
ACC	2	263	SUBJECT*ACC	1.56	.2446
SUBJECT*TASK	35	4974	ERROR	2.77	.0002
SUBJECT*ACC	14	1179	ERROR	1.64	.0894
TASK*ACC	10	611	ERROR	1.19	.3115
ERROR	69	3556			
TOTAL	142	12153			

(I) MAIN EFFECTS FOR TASK (LSD = 7.0)

TASK	MEAN (%)
1/S2-4	88.5
0-4	92.1
1/S2-2	93.4
1/S-4	93.5
1/S-2	93.8
0-2	96.8

(II) MAIN EFFECTS FOR ACC (LSD = 4.0)

ACC	MEAN (%)
HIGH	91.1
BASE	93.9
LOW	94.1

(III) COMPARISON OF PLANT MEANS(LSD = 4.9)

PLANT	MEAN (%)
1/S2	[illegible]
1/S	93.7
0	94.4

(IV) COMPARISON OF TARGETS MEANS(LSD = 4.0)

TARGETS	MEAN (%)
4	91.4
2	94.6

TABLE 7A. ANOVA TABLE, SECONDARY TASK REACTION TIME AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	8	.1356	ERROR	34.81	.0001
TASK	5	.0327	SUBJECT*TASK	6.09	.0003
NOISE	2	.0058	SUBJECT*NOISE	5.14	.0189
SUBJECT*TASK	40	.0430	ERROR	2.21	.0013
SUBJECT*NOISE	16	.0089	ERROR	1.15	.3274
TASK*NOISE	10	.0049	ERROR	1.01	.4448
ERROR	80	.0390			
TOTAL	161	.2699			

(I) MAIN EFFECTS FOR TASK (LSD = .018)

TASK	MEAN (SECONDS)
0-2	.674
1/S-2	.689
1/S2-2	.699
0-4	.701
1/S-4	.713
1/S2-4	.715

(II) MAIN EFFECTS FOR NOISE (LSD = .010)

NOISE	MEAN (SECONDS)
100	.694
90	.695
A	.707

(III) COMPARISON OF PLANT MEANS(LSD = .013)

PLANT	MEAN (SECONDS)
0	.687
1/S	.701
1/S2	.707

(IV) COMPARISON OF TARGETS MEANS(LSD = .010)

TARGETS	MEAN (SECONDS)
2	.687
4	.710

TABLE 7B. ANOVA TABLE, SECONDARY TASK REACTION TIME AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	7	.131	ERROR	11.31	.0001
TASK	5	.087	SUBJECT*TASK	7.70	.0001
ACC	2	.002	SUBJECT*ACC	1.29	.3056
SUBJECT*TASK	35	.079	ERROR	1.37	.1323
SUBJECT*ACC	14	.012	ERROR	0.53	.9046
TASK*ACC	10	.006	ERROR	0.37	.9541
ERROR	70	.116			
TOTAL	143	.433			

(I) MAIN EFFECTS FOR TASK (LSD = .028)

TASK	MEAN (SECONDS)
0-2	.624
1/S-2	.652
0-4	.672
1/S2-2	.673
1/S-4	.688
1/S2-4	.700

(II) MAIN EFFECTS FOR ACC (LSD = .013)

ACC	MEAN (SECONDS)
LOW	.663
BASE	.670
HIGH	.672

(III) COMPARISON OF PLANT MEANS(LSD = .020)

PLANT	MEAN (SECONDS)
0	.648
1/S	.670
1/S2	.687

(IV) COMPARISON OF TARGETS MEANS(LSD = .016)

TARGETS	MEAN (SECONDS)
2	.650
4	.687

TABLE 8A. ANOVA TABLE, MAN-MACHINE RESPONSE TIME AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	8	.6771	ERROR	10.21	.0001
TASK	5	.9260	SUBJECT*TASK	8.01	.0001
NOISE	2	.0294	SUBJECT*NOISE	2.83	.0888
SUBJECT*TASK	40	.9247	ERROR	2.79	.0001
SUBJECT*NOISE	16	.0831	ERROR	0.63	.8530
TASK*NOISE	10	.1779	ERROR	2.15	.0299
ERROR	80	.6630			
TOTAL	161	3.4811			

(I) MAIN EFFECTS FOR TASK (LSD = .084)

TASK	MEAN (SECONDS)
1/S-2	.752
1/S-4	.753
1/S-0	.7o6
1/S2-0	.884
1/S2-2	.913
1/S2-4	.922

(II) MAIN EFFECTS FOR NOISE (LSD = .029)

NOISE	MEAN (SECONDS)
100	.812
A	.840
90	.842

(III) COMPARISON OF PLANT MEANS(LSD = .048)

PLANT	MEAN (SECONDS)
1/S	.757
1/S2	.906

(IV) COMPARISON OF TARGETS MEANS(LSD = .059)

TARGETS	MEAN (SECONDS)
0	.825
2	.832
4	.838

TABLE 8B. ANOVA TABLE, MAN-MACHINE RESPONSE TIME AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	6	.420	ERROR	7.30	.0001
TASK	5	1.819	SUBJECT*TASK	31.42	.0001
ACC	2	.080	SUBJECT*ACC	4.22	.0410
SUBJECT*TASK	30	.347	ERROR	1.21	.2645
SUBJECT*ACC	12	.114	ERROR	0.99	.4715
TASK*ACC	10	.042	ERROR	0.44	.9219
ERROR	60	.576			
TOTAL	125	3.398			

(I) MAIN EFFECTS FOR TASK (LSD = .068)

TASK	MEAN (SECONDS)
1/S-2	.694
1/S-4	.695
1/S-0	.707
1/S2-2	.926
1/S2-0	.938
1/S2-4	.951

(II) MAIN EFFECTS FOR ACC (LSD = .046)

ACC	MEAN (SECONDS)
LOW	.784
HIGH	.828
BASE	.844

(III) COMPARISON OF PLANT MEANS(LSD = .039)

PLANT	MEAN (SECONDS)
1/S	.699
1/S2	.938

(IV) COMPARISON OF TARGETS MEANS(LSD = .048)

TARGETS	MEAN (SECONDS)
2	.810
0	.823
4	.823

TABLE 9A. ANOVA TABLE, HEAPT RATE AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	6	18395	ERROR	514.50	.0001
TASK	7	142	SUBJECT*TASK	2.15	.0586
NOISE	2	27	SUBJFCT*NOISE	1.68	.2269
SUBJECT*TASK	42	396	ERROR	1.58	.0397
SUBJECT*NOISE	12	97	ERROR	1.36	.2029
TASK*NOISE	14	122	ERROR	1.46	.1440
ERROR	80	477			
TOTAL	163	19654			

(I) MAIN EFFECTS FOR TASK (LSD = 1.9)

TASK	MEAN (BPM)
0-2	72.3
0-4	73.4
1/S-0	73.5
1/S2-4	74.0
1/S2-2	74.5
1/S2-0	74.8
1/S-2	74.8
1/S-4	75.4

(II) MAIN EFFECTS FOR NOISE (LSD = 1.2)

NOISE	MEAN (BPM)
A	73.7
100	73.9
90	74.7

(III) COMPARISON OF PLANT MEANS (LSD = 1.4)

PLANT	MEAN (BPM)
0	72.9
1/S2	74.2
1/S	75.1

(IV) COMPARISON OF TARGETS MEANS (LSD = 1.4)

TARGETS	MEAN (BPM)
0	74.1
2	74.6
4	74.7

TABLE 9B. ANOVA TABLE, HEART RATE AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	7	20082	ERROR	79.71	.0001
TASK	7	905	SUBJECT*TASK	2.27	.0443
ACC	2	22161	SUBJECT*ACC	34.30	.0001
SUBJECT*TASK	49	2797	ERROR	1.59	.0271
SUBJECT*ACC	14	4523	ERROR	8.98	.0001
TASK*ACC	14	1511	ERROR	3.00	.0007
ERROR	98	3527			
TOTAL	191	55505			

(I) MAIN EFFECTS FOR TASK (LSD = 4.4)

TASK	MEAN (BPM)
1/S-0	87.7
0-2	88.5
0-4	89.8
1/S-2	92.4
1/S2-0	92.5
1/S-4	93.0
1/S2-2	93.3
1/S2-4	93.6

(II) MAIN EFFECTS FOR ACC (LSD = 6.8)

ACC	MEAN (BPM)
BASE	79.0
LOW	89.8
HIGH	105.2

(III) COMPARISON OF PLANT MEANS(LSD = 3.1)

PLANT	MEAN (BPM)
0	89.1
1/S	92.7
1/S2	93.5

(IV) COMPARISON OF TARGETS MEANS(LSD = 3.1)

TARGETS	MEAN (BPM)
0	90.1
2	92.9
4	93.3

TABLE 10A. ANOVA TABLE, TOTAL EYE BLINKS AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	7	5462	ERROR	61.84	.0001
TASK	7	4121	SUBJECT*TASK	17.26	.0001
ACC	2	12	SUBJECT*NOISE	0.69	.5164
SUBJECT*TASK	49	1671	ERROR	2.70	.0001
SUBJECT*NOISE	14	118	ERROR	0.67	.7986
TASK*NOISE	14	141	ERROR	0.80	.6664
ERROR	97	1224			
TOTAL	190	12811			

(I) MAIN EFFECTS FOR TASK (LSD = 3.4)

TASK	MEAN (Blinks/Exposures)
1/S2-0	6.9
1/S-0	7.0
1/S-2	7.4
1/S2-4	7.7
1/S-4	7.7
1/S2-2	7.8
0-4	17.0
0-2	19.1

(II) MAIN EFFECTS FOR NOISE (LSD = 1.1)

NOISE	MEAN (Blinks/Exposures)
90	9.7
A	10.1
100	10.3

(III) COMPARISON OF PLANT MEANS(LSD = 2.4)

PLANT	MEAN (Blinks/Exposure)
1/S	7.6
1/S2	7.7
0	18.0

(IV) COMPARISON OF TARGETS MEANS(LSD = 2.4)

TARGETS	MEAN (Blinks/Exposure)
0	6.9
2	7.6
4	7.7

TABLE 10B. ANOVA TABLE, TOTAL EYE BLINKS AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	6	16458	ERROR	101.98	.0001
TASK	7	3921	SUBJECT*TASK	9.95	.0001
ACC	2	1920	SUBJECT*ACC	5.67	.0184
SUBJECT*TASK	42	2363	ERROR	2.09	.0021
SUBJECT*ACC	12	2031	ERROR	6.29	.0001
TASK*ACC	14	396	ERROR	1.05	.4131
ERROR	84	2262			
TOTAL	167	29351			

(I) MAIN EFFECTS FOR TASK (LSD = 4.7)

TASK	MEAN (Blinks/Exposure)
1/S2-0	12.1
1/S-4	13.2
1/S2-2	13.2
1/S-2	13.3
1/S-0	13.5
1/S2-4	15.2
0-2	24.1
0-4	24.8

(II) MAIN EFFECTS FOR ACC (LSD = 5.4)

ACC	MEAN (Blinks/Exposure)
BASE	12.9
LOW	14.9
HIGH	20.8

(III) COMPARISON OF PLANT MEANS(LSD = 3.3)

PLANT	MEAN (Blinks/Exposures)
1/S	13.3
1/S2	14.2
0	24.5

(IV) COMPARISON OF TARGETS MEANS(LSD = 3.3)

TARGETS	MEAN (Blinks/Exposure)
0	12.8
2	13.3
4	14.2

TABLE 11A. ANOVA TABLE, BLINK DURATION AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	5	21324	ERROR	8.53	.0001
TASK	7	4684	SUBJECT*TASK	1.71	.1387
NOISE	2	1433	SUBJECT*NOISE	1.12	.3649
SUBJECT*TASK	35	13694	ERROR	0.78	.7841
SUBJECT*NOISE	10	6415	ERROR	1.28	.2582
TASK*ACC	14	4810	ERROR	0.69	.7791
ERROR	67	33514			
TOTAL	140	86192			

(I) MAIN EFFECTS FOR TASK (LSD = 13)

TASK	MEAN (Milliseconds)
1/S-2	128
1/S2-4	129
1/S2-0	129
1/S-0	131
1/S-4	131
1/S2-2	135
0-4	141
0-2	145

(II) MAIN EFFECTS FOR NOISE (LSD = 12)

NOISE	MEAN (Milliseconds)
100	129
90	134
A	137

(III) COMPARISON OF PLANT MEANS(LSD = 10)

PLANT	MEAN (Milliseconds)
1/S	129
1/S2	132
0	143

(IV) COMPARISON OF TARGETS MEANS(LSD - 10)

TARGETS	MEAN (Milliseconds)
0	130
4	130
2	131

TABLE 11B. ANOVA TABLE, BLINK DURATION AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	5	22425	ERROR	14.68	.0001
TASK	7	7491	SUBJECT*TASK	3.17	.0105
ACC	2	9614	SUBJECT*ACC	12.92	.0017
SUBJECT*TASK	35	11811	ERROR	1.10	.3586
SUBJECT*ACC	10	3720	ERROR	1.22	.2974
TASK*ACC	14	9132	ERROR	2.14	.0212
ERROR	63	19245			
TOTAL	136	83326			

(I) MAIN EFFECTS FOR TASK (LSD = 12)

TASK	MEAN (Milliseconds)
$1/S^2$-2	109
1/S-4	110
1/S2-4	121
1/S-0	126
1/S2-2	127
0-2	128
1/S-2	129
0-4	130

(II) MAIN EFFECTS FOR ACC (LSD = 9)

ACC	MEAN (Milliseconds)
HIGH	116
LOW	117
BASE	134

(III) COMPARISON OF PLANT MEANS(LSD = 9)

PLANT	MEAN (Milliseconds)
1/S	120
1/S2	124
0	129

(IV) COMPARISON OF TARGETS MEANS(LSD = 9)

TARGETS	MEAN (Milliseconds)
4	115
0	118
2	128

TABLE 12A. ANOVA TABLE, P300 LATENCY AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	4	205231	ERROR	23.65	.0001
TASK	7	43284	SUBJECT*TASK	1.06	.4140
NOISE	2	4363	SUBJECT*NOISE	0.44	.6558
SUBJECT*TASK	28	163316	ERROR	2.69	.0008
SUBJECT*NOISE	8	39220	ERROR	2.26	.0361
TASK*NOISE	14	41724	ERROR	1.37	.1969
ERROR	56	121499			
TOTAL	119	618638			

(I) MAIN EFFECTS FOR TASK (LSD = 57)

TASK	MEAN (Milliseconds)
1/S-0	449
1/S2-0	452
0-2	467
0-4	478
1/S-4	485
1/S2-4	489
1/S-2	497
1/S2-2	506

(II) MAIN EFFECTS FOR NOISE (LSD = 36)

NOISE	MEAN (Milliseconds)
100	470
90	479
A	485

(III) COMPARISON OF PLANT MEANS(LSD 40)

PLANT	MEAN (Milliseconds)
0	473
1/S	491
1/S2	497

(IV) COMPARISON OF TARGETS MEANS(LSD = 40)

TARGETS	MEAN (Milliseconds)
0	451
4	487
2	501

TABLE 12B. ANOVA TABLE, P300 LATENCY AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	7	73013	ERROR	5.15	.0001
TASK	7	104944	SUBJECT*TASK	1.27	.2846
ACC	2	6165	SUBJECT*ACC	1.27	.3102
SUBJECT*TASK	49	578403	ERROR	5.82	.0001
SUBJECT*ACC	14	33868	ERROR	1.19	.2934
TASK*ACC	14	26666	ERROR	0.94	.5203
ERROR	94	190536			
TOTAL	187	1016373			

(I) MAIN EFFECTS FOR TASK (LSD 63)

TASK	MEAN (Milliseconds)
1/S-0	417
1/S2-0	430
0-2	443
1/S2-0	463
0-4	465
1/S2-4	479
1/S2-2	480
1/S-4	488

(II) MAIN EFFECTS FOR ACC (LSD = 19)

ACC	MEAN (Milliseconds)
BASE	450
LOW	461
HIGH	463

(III) COMPARISON OF PLANT MEANS(LSD 45)

PLANT	MEAN (Milliseconds)
0	454
1/S	459
1/S2	480

(IV) COMPARISON OF TARGETS MEANS(LSD = 45)

TARGETS	MEAN (Milliseconds)
0	439
2	455
4	483

TABLE 13A. ANOVA TABLE, P300 AMPLITUDE AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	4	721	ERROR	7.43	.0001
TASK	7	908	SUBJECT*TASK	2.96	.0187
NOISE	2	49	SUBJECT*NOISE	0.61	.5675
SUBJECT*TASK	28	1226	ERROR	1.80	.0303
SUBJECT*NOISE	8	323	ERROR	1.66	.1276
TASK*NOISE	14	534	ERROR	1.57	.1169
ERROR	56	1359			
TOTAL	119	5120			

(I) MAIN EFFECTS FOR TASK (LSD = 4.9)

TASK	MEAN (Microvolts)
1/S2-0	7.2
0-4	11.4
1/S-4	11.9
1/S-2	12.6
1/S-0	12.7
0-2	15.5
1/S2-2	15.7
1/S2-4	16.1

(II) MAIN EFFECTS FOR NOISE (LSD = 3.3)

NOISE	MEAN (Microvolts)
100	12.1
90	12.8
A	13.7

(III) COMPARISON OF PLANT MEANS(LSD 3.5)

PLANT	MEAN (Microvolts)
1/S	12.3
0	13.4
1/S2	15.9

(IV) COMPARISON OF TARGETS MEANS(LSD = 3.5)

TARGETS	MEAN (Microvolts)
0	9.9
4	14.0
2	14.2

TABLE 13B. ANOVA TABLE, P300 AMPLITUDE AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	7	1623	ERROR	3.29	.0036
TASK	7	1465	SUBJECT*TASK	1.21	.3165
ACC	2	53	SUBJECT*ACC	0.34	.7173
SUBJECT*TASK	49	8489	ERROR	2.46	.0001
SUBJECT*ACC	14	1082	ERROR	1.10	.3708
TASK*ACC	14	1295	ERROR	1.31	.2150
ERROR	92	6480			
TOTAL	185	20855			

(I) MAIN EFFECTS FOR TASK (LSD = 7.6)

TASK	MEAN (Microvolts)
1/S-0	10.8
1/S-2	11.2
1/S2-0	12.1
0-2	14.9
1/S2-2	15.0
1/S-4	16.7
1/S2-4	18.2
0-4	18.6

(II) MAIN EFFECTS FOR ACC (LSD = 3.3)

ACC	MEAN (Microvolts)
BASE	14.0
LOW	14.8
HIGH	15.3

(III) COMPARISON OF PLANT MEANS(LSD - 5.4)

PLANT	MEAN (Microvolts)
1/S	13.9
1/S2	16.6
0	16.8

(IV) COMPARISON OF TARGETS MEANS(LSD = 5.4)

TARGETS	MEAN (Microvolts)
0	11.5
2	13.1
4	17.4

TABLE 14A. ANOVA TABLE, EMG STANDARD DEVIATION (STD) AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	5	26000	ERROR	45.52	.0001
TASK	7	18809	SUBJECT*TASK	3.41	.0070
NOISE	2	103	SUBJECT*NOISE	0.54	.5965
SUBJECT*TASK	35	27614	ERROR	6.91	.0001
SUBJECT*NOISE	10	946	ERROR	0.83	.6017
TASK*NOISE	14	1538	ERROR	0.96	.5006
ERROR	68	7768			
TOTAL	141	84200			

(I) MAIN EFFECTS FOR TASK (LSD = 19.0)

TASK	MEAN (Millivolts)
1/S-0	42.9
0-2	43.9
1/S2-0	48.4
0-4	55.6
1/S-2	60.2
1/S-4	66.1
1/S2-2	73.1
1/S2-4	74.0

(II) MAIN EFFECTS FOR NOISE (LSD = 4.4)

NOISE	MEAN (Millivolts)
90	57.2
A	57.7
100	59.2

(III) COMPARISON OF PLANT MEANS(LSD = 13.4)

PLANT	MEAN (Millivolts)
0	49.8
1/S	63.1
1/S2	73.5

(IV) COMPARISON OF TARGETS MEANS(LSD = 13.4)

TARGETS	MEAN (Millivolts)
0	45.6
2	66.7
4	70.0

TABLE 14B. ANOVA TABLE, EMG STANDARD DEVIATION (STD) AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	5	5786	ERROR	28.04	.0001
TASK	7	2385	SUBJECT*TASK	4.21	.0018
ACC	2	144	SUBJECT*ACC	4.29	.0452
SUBJECT*TASK	35	2832	ERROR	1.96	.0084
SUBJECT*ACC	10	167	ERROR	0.41	.9396
TASK*ACC	14	577	ERROR	1.00	.4647
ERROR	70	2888			
TOTAL	143	14780			

(I) MAIN EFFECTS FOR TASK (LSD = 6.1)

TASK	MEAN (Millivolts)
0-2	14.8
1/S2-0	17.0
0-4	17.0
1/S-0	17.1
1/S-2	19.3
1/S-4	21.2
1/S2-4	26.2
1/S2-2	26.3

(II) MAIN EFFECTS FOR ACC (LSD = 1.9)

ACC	MEAN (Millivolts)
BASE	19.0
LOW	19.3
HIGH	21.3

(III) COMPARISON OF PLANT MEANS(LSD = 4.3)

PLANT	MEAN (Millivolts)
0	15.9
1/S	20.2
1/S2	20.2

(IV) COMPARISON OF TARGETS MEANS(LSD = 4.3)

TARGETS	MEAN (Millivolts)
0	17.0
2	22.8
4	23.7

TABLE 15. ANOVA TABLE, MEAN ARTERIAL BLOOD PRESSURE AND NOISE

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	8	10971	ERROR	87.15	.0001
TASK	7	196	SUBJECT*TASK	1.86	.0944
NOISE	2	92	SUBJECT*NOISE	2.46	.1172
SUBJECT*TASK	56	846	ERROR	0.96	.5596
SUBJECT*NOISE	16	299	ERROR	1.19	.2876
TASK*NOISE	14	176	ERROR	0.80	.6680
ERROR	112	1762			
TOTAL	215	14343			

(I) MAIN EFFECTS FOR TASK (LSD = 2.1)

TASK	MEAN (mm Hg)
0-2	93.2
0-4	93.9
1/S-2	94.2
1/S-0	94.7
1/S2-4	95.4
1/S2-0	95.5
1/S-4	95.9
1/S2-2	96.0

(II) MAIN EFFECTS FOR NOISE (LSD = 1.5)

NOISE	MEAN (mm Hg)
A	94.0
100	95.1
90	95.5

(III) COMPARISON OF PLANT MEANS(LSD = 1.5)

PLANT	MEAN (mm Hg)
0	93.6
1/S	95.1
1/S2	95.7

(IV) COMPARISON OF TARGETS MEANS(LSD - 1.5)

TARGETS	MEAN (mm Hg)
0	95.1
2	95.1
4	95.7

TABLE 16. ANOVA TABLE, PERCENT ARTERIAL OXYGEN SATURATION AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	3	517	ERROR	16.91	.0001
TASK	7	24	SUBJECT*TASK	0.31	.9390
ACC	2	7	SUBJECT*ACC	0.65	.5571
SUBJECT*TASK	21	230	ERROR	1.08	.4067
SUBJECT*ACC	6	33	ERROR	0.54	.7724
TASK*ACC	14	63	ERROR	0.44	.9518
ERROR	42	428			
TOTAL	95	1302			

(I) MAIN EFFECTS FOR TASK (LSD = 2.8)

TASK	MEAN (%)
0-4	93.3
1/S2-0	94.4
0-2	94.5
1/S-0	94.6
1/S-4	94.7
1/S-2	94.8
1/S2-4	94.9
1/S2-2	95.1

(II) MAIN EFFECTS FOR ACC (LSD = 1.4)

ACC	MEAN (%)
HIGH	94.3
BASE	94.5
LOW	94.9

(III) COMPARISON OF PLANT MEANS(LSD = 2.0)

PLANT	MEAN (%)
0	93.9
1/S	94.8
1/S2	95.0

(IV) COMPARISON OF TARGETS MEANS(LSD - 2.0)

TARGETS	MEAN (%)
0	94.5
4	94.8
2	95.0

TABLE 17. ANOVA TABLE, PERCENT TEMPORAL ARTERY FLOW VELOCITY AND ACCELERATION

SOURCE	DF	SUM OF SQUARES	ERROR TERM	F-VALUE	P-VALUE
SUBJECT	6	2436	ERROR	3.70	.0048
TASK	7	1262	SUBJECT*TASK	1.22	.3135
ACC	1	6285	SUBJECT*ACC	20.64	.0039
SUBJECT*TASK	42	6205	ERROR	1.35	.1694
SUBJECT*ACC	6	1827	ERROR	2.78	.0230
TASK*ACC	7	871	ERROR	1.13	.3603
ERROR	42	4608			
TOTAL	111	23494			

(I) MAIN EFFECTS FOR TASK (LSD = 9.3)

TASK	MEAN (%)
1/S-4	16.1
1/S-0	19.2
0-4	22.0
1/S2-0	22.6
1S2-2	23.0
0-2	23.4
1/S-2	25.6
1/S2-4	27.7

(II) MAIN EFFECTS FOR ACC (LSD = 8.1)

ACC	MEAN (%)
HIGH	15.0
LOW	29.9

(III) COMPARISON OF PLANT MEANS(LSD = 6.6)

PLANT	MEAN (%)
1/S	20.8
0	22.7
1/S2	25.4

(IV) COMPARISON OF TARGETS MEANS(LSD = 6.6)

TARGETS	MEAN (%)
0	20.9
4	21.9
2	24.3

TABLE 18. SPEARMAN CORRELATION COEFFICIENTS, P-VALUES, AND NUMBER OF OBSERVATIONS--EXPERIMENT I

		SWAT	Score	Percent Hits	RT	MMRT	HR	MAP	P3 LAT	P3 AMP	Total Blinks	Blink Duration	EMG Standard
SUBJECTIVE MEASURE	SWAT	1.000 .000 24	.5191 .0273 18	-.3994 .1006 18	.4345 .0716 18	.3271 .1851 18	.4974 .0134 24	.6305 .0006 24	.3275 .1182 24	.3261 .1199 24	-.2911 .1676 24	-.5755 .0033 24	.7626 .0001 24
PERFORMANCE MEASURES	Score		1.000 .000 18	-.5524 .0625 12	.4456 .1517 12	.6801 .0019 18	.0588 .8167 18	.2755 .2684 18	.1290 .6099 18	.3643 .1372 18	.0331 .8963 18	-.0825 .7440 18	.6512 .0034 18
	Percent Hits			1.000 .000 18	-.8406 .0001 18	-.2797 .3785 12	-.3292 .1822 18	-.3354 .1780 18	.1002 .6925 18	-.1744 .4888 18	.0754 .7653 18	.3311 .1796 18	-.5439 .0195 18
	RT				1.000 .000 18	.2308 .4705 12	.3952 .1045 18	.43[illegible] .06[illegible] 18	-.1156 .6477 18	.2549 .3073 18	-.2199 .38[illegible] 18	-.3208 .1944 18	.6244 .0056 18
	MMRT					1.000 .000 18	.0093 .9708 18	.1785 .4[illegible] 18	.2219 .3762 18	.4118 .0895 18	.0527 [illegible] 18	.1738 .4903 18	.4407 .0672 18
PHYSIOLOGICAL MEASURES	HR						1.000 .000 24	[illegible] .0055 24	.2930 .1635 24	-.0435 .8401 24	-.3032 .1497 24	-.5207 .0091 24	.3365 .1079 24
	MAP							1.000 .000 24	.0309 .8861 24	.1096 .6103 24	-.2597 .2203 24	-.4240 .0389 24	.4543 .0256 24
	P3 LAT								1.000 .000 24	.1949 .3615 24	-.1754 .4[illegible] 24	.0324 .8804 24	.5163 .0098 24
	P3 AMP									1.000 .000 24	.1447 .4852 24	-.0267 .8940 24	.4361 .0166 24
	Total Blinks										1.000 .000 24	.3906 .0592 24	-.1366 .5244 24
	Blink Duration											1.000 .000 24	-.3413 .1026 24
	EMG Standard												1.000 .000 24

KEY: 1.000 - Top No. = Correlation Coefficient
.000 - Middle No. = P-Value
24 - Bottom No. = No. of Observations

TABLE 19. MEANS AND STANDARD DEVIATIONS OF SUBJECTS--EXPERIMENT 1

Task	Noise	Mean SWAT	STD DEV SWAT	Mean Map	STD DEV Map	Mean Percent Hits	STD DEV Percent Hits	Mean Reaction Time	STD DEV Reaction Time	Mean Score	STD DEV Score	Mean Man-Machine Response Time	STD DEV Man-Machine Response Time
0-2	A	3.5	6.2	93.0	9.8	91.5	10.3	0.695	0.059	--	--	--	--
0-2	90	7.1	8.9	92.9	8.7	93.0	7.7	0.668	0.033	--	--	--	--
0-2	100	17.9	14.0	93.7	9.9	93.7	6.1	0.658	0.033	--	--	--	--
0-4	A	8.1	9.5	94.9	8.3	86.7	15.3	0.713	0.042	--	--	--	--
0-4	90	14.5	11.2	94.2	7.7	87.2	10.2	0.698	0.032	--	--	--	--
0-4	100	21.6	11.7	92.7	5.8	88.2	12.7	0.692	0.050	--	--	--	--
1/S-0	A	9.6	13.3	93.2	9.1	--	--	--	--	11.3	2.7	0.802	0.127
1/S-0	90	16.8	[illegible]	93.1	7.6	--	--	--	--	11.7	2.1	0.776	0.105
1/S-0	100	21.7	13.1	95.6	5.9	--	--	--	--	11.8	2.7	0.723	0.102
1/S-2	A	18.1	17.3	92.4	7.6	93.7	6.3	0.689	0.047	13.3	2.7	0.702	0.094
1/S-2	90	27.1	13.4	94.[illegible]	7.2	89.[illegible]	7.1	0.684	0.033	11.9	1.4	0.784	0.100
1/S-2	100	24.9	9.0	95.5	5.9	92.1	5.0	0.692	0.025	14.1	2.4	0.767	0.174
1/S-4	A	26.1	9.9	94.4	7.5	86.0	9.0	0.721	0.038	12.7	1.2	0.823	0.110
1/S-4	90	31.5	12.9	96.2	6.7	88.2	7.8	0.711	0.032	14.3	4.0	0.732	0.050
1/S-4	100	36.7	18.7	97.2	9.9	86.5	8.8	0.707	0.041	12.7	2.2	0.704	0.093
1/S2-0	A	16.1	8.9	95.1	8.7	--	--	--	--	21.3	5.4	0.915	0.142
1/S2-0	90	22.8	18.7	97.7	8.2	--	--	--	--	21.9	10.6	0.870	0.208
1/S2-0	100	24.9	10.9	93.7	10.8	--	--	--	--	20.2	7.3	0.866	0.114
1/S2-2	A	23.5	16.1	94.6	9.9	86.3	10.4	0.704	0.044	25.0	6.8	0.896	0.150
1/S2-2	90	32.2	12.8	97.3	7.8	91.9	7.0	0.695	0.054	21.1	6.9	0.907	0.107
1/S2-2	100	44.8	13.5	96.3	9.[illegible]	[illegible]	5.7	0.694	0.027	21.3	5.3	0.935	0.171
1/S2-4	A	34.0	13.8	94.2	8.9	[illegible]	7.0	0.719	0.033	23.0	6.8	0.901	0.127
1/S2-4	90	38.1	12.6	95.7	9.9	87.4	13.6	0.711	0.034	22.8	5.4	0.983	0.150
1/S2-4	100	55.6	16.9	96.3	9.7	79.5	9.5	0.716	0.035	28.1	6.4	0.882	0.069
No. of Subjects:		N=9		N=9		N=9		N=9		N=9		N=9	

TABLE 19. MEANS AND STANDARD DEVIATIONS OF SUBJECTS--EXPERIMENT 1 (continued)

Task	Noise	Mean Heart Rate	STD DEV Heart Rate	Mean Total Blinks	STD DEV Total Blinks	Mean Blink Duration	STD DEV Blink Duration	Mean P300 Latency	STD DEV P300 Latency	Mean P300 Amplitude	STD DEV P300 Amplitude	Mean EMG Standard	STD DEV EMG Standard
0-2	A	72.7	11.0	18.9	8.9	149	15	466	79	22.7	4.8	45.5	15.0
0-2	90	71.5	11.4	19.8	11.6	137	40	438	51	12.9	12.0	40.6	13.7
0-2	100	72.9	11.5	18.6	9.7	148	20	498	33	10.8	6.2	45.7	22.3
0-4	A	73.9	10.5	19.3	7.2	143	11	470	53	10.8	6.1	51.1	21.4
0-4	90	73.8	12.1	15.0	4.9	136	15	481	96	12.8	6.4	59.8	18.0
0-4	100	72.6	10.6	16.7	9.5	143	23	485	84	10.6	5.3	55.8	22.5
1/S-0	A	72.8	12.1	5.5	6.2	143	23	500	110	9.5	4.2	43.0	28.2
1/S-0	90	73.5	11.7	7.4	7.7	140	17	440	93	14.4	5.1	39.8	26.8
1/S-0	100	74.2	13.2	8.1	6.2	109	36	409	107	14.1	5.9	45.9	33.7
1/S-2	A	72.8	13.1	6.6	5.7	133	19	482	55	13.9	6.2	60.7	20.3
1/S-2	90	77.2	9.9	8.0	7.2	131	16	508	61	13.0	3.9	58.1	24.1
1/S-2	100	74.5	13.1	7.8	9.1	119	25	500	60	11.0	1.2	61.8	16.7
1/S-4	A	76.2	8.4	8.3	8.2	133	20	492	43	13.0	4.4	66.1	10.6
1/S-4	90	75.7	11.2	6.6	6.1	131	39	491	50	11.7	9.6	68.8	21.9
1/S-4	100	74.4	13.0	8.4	5.6	130	20	472	74	10.9	4.5	63.3	16.7
1/S2-0	A	73.2	10.7	6.6	6.6	128	17	457	48	8.9	7.6	51.4	25.8
1/S2-0	90	75.3	8.5	7.1	6.4	135	20	463	102	6.0	4.9	50.9	35.3
1/S2-0	100	75.7	7.9	6.9	5.5	124	13	438	64	6.6	4.0	42.8	31.4
1/S2-2	A	74.5	13.1	8.1	5.1	133	38	535	100	15.0	3.1	69.3	17.9
1/S2-2	90	75.5	10.3	6.6	5.0	139	44	502	66	14.6	2.8	73.2	30.2
1/S2-2	100	73.3	13.2	9.6	6.8	134	36	481	73	17.6	10.6	76.8	21.9
1/S2-4	A	73.6	11.8	8.0	7.9	134	29	479	43	15.7	4.1	74.2	26.0
1/S2-4	90	74.8	13.4	7.4	5.2	127	17	508	83	17.2	7.3	66.3	19.5
1/S2-4	100	73.5	13.8	7.7	5.5	125	23	480	70	15.4	5.7	81.5	13.1
No. of Subjects:		N=7		N=8		N=6		N=5		N=5		N=6	

TABLE 20. SPEARMAN CORRELATION COEFFICIENTS, P-VALUES, AND NUMBER OF OBSERVATIONS--EXPERIMENT II

		SWAT	Score	Percent Hits	RT	MMRT	HR	P3 LAT	P3 AMP	Total Blinks	Blink Duration	EMG Standard
SUBJECTIVE MEASURE	SWAT	1.000 .000 24	.6694 .0024 18	-.5408 .0205 18	.4498 .0611 18	.3024 .2226 18	.7137 .0001 24	.4522 .0265 24	.1419 .5085 24	.0483 .8226 24	-.3404 .1036 24	.6162 .0014 24
PERFORMANCE MEASURES	Score		1.000 .000 18	-.4912 .1048 12	.4035 .1933 12	.7967 .0001 18	.3114 .2084 18	.6656 .0026 18	.4470 .0629 18	.2502 .3160 18	-.2464 .3244 18	.5173 .0279 18
	Percent Hits			1.000 .000 18	-.6058 .0077 19	-.3566 .2551 12	-.3003 .2260 18	-.2798 .2608 18	-.1785 .4784 18	.0237 .9255 18	.3738 .1265 18	-.4489 .0617 18
	RT				1.000 .000 18	.32[illegible]7 .2969 12	.1042 .6806 18	.6495 .0035 18	.3065 .2161 18	-.3767 .1234 18	-.4048 .0957 18	.6471 .0037 18
	MMRT					1.000 .000 18	-.0464 .8548 18	.3727 .1277 18	.3210 .1941 18	-.0651 .7976 18	.0289 .9093 18	.3375 .1708 18
PHYSIOLOGICAL MEASURES	HR						1.000 .000 24	.3714 .0740 24	.1756 .4117 24	.4197 .0412 24	-.6072 .0017 24	.1739 .4164 24
	P3 LAT							1.000 .000 24	.4744 .0192 24	.0526 .8070 24	-.3459 .0978 24	.6127 .0015 24
	P3 AMP								1.000 .000 24	.4923 .0145 24	-.0278 .8973 24	.1817 .3964 24
	Total Blinks									1.000 .000 24	-.0498 .8172 24	-.3079 .1433 24
	Blink Duration										1.000 .000 24	-.0022 .9920 24
	EMG Standard											1.000 .000 24

KEY: 1.000 - Top No. = Correlation Coefficient
.000 - Middle No. = P-Value
24 - Bottom No. = No. of Observations

TABLE 21. MEANS AND STANDARD DEVIATIONS OF SUBJECTS--EXPERIMENT II

Task	ACC	Mean SWAT	STD DEV SWAT	Mean Doppler	STD DEV Doppler	Mean SAU2	STD DEV SAU2	Mean Percent Hits	STD DEV Percent Hits	Mean Reaction Time	STD DEV Reaction Time	Mean Score	STD DEV Score	Mean Man-Machine Response Time	STD DEV Man-Machine Response Time
0-2	Base	0.0	0.0	100.0	0.0	94.0	4.2	99.2	2.4	0.625	0.041	--	--	--	--
0-2	Low	0.0	0.0	30.3	11.7	95.8	3.3	98.2	5.1	0.613	0.053	--	--	--	--
0-2	High	26.0	20.1	16.6	6.0	93.8	2.2	92.9	6.9	0.634	0.057	--	--	--	--
0-4	Base	2.2	6.2	100.0	0.0	94.3	3.5	91.6	11.1	0.673	0.056	--	--	--	--
0-4	Low	0.0	0.0	29.7	21.1	92.5	6.0	94.9	7.7	0.665	0.054	--	--	--	--
0-4	High	26.5	17.8	14.3	3.8	93.0	6.7	89.8	9.4	0.677	0.040	--	--	--	--
1/S-0	Base	6.8	13.5	100.0	0.0	95.5	1.0	--	--	--	--	11.8	1.8	0.737	0.070
1/S-0	Low	13.0	17.5	27.3	19.8	95.3	2.5	--	--	--	--	14.0	2.2	0.692	0.051
1/S-0	High	26.4	15.6	11.1	5.3	93.0	4.2	--	--	--	--	13.6	1.2	0.694	0.110
1/S-2	Base	10.6	12.1	100.0	0.0	94.3	3.9	94.3	5.5	0.650	0.059	14.0	1.1	0.713	0.046
1/S-2	Low	23.9	18.0	33.3	16.3	95.8	4.5	98.1	5.4	0.641	0.044	14.0	1.9	0.661	0.102
1/S-2	High	40.6	16.4	17.9	11.7	94.5	4.4	89.1	10.6	0.665	0.044	16.6	3.8	0.708	0.115
1/S-4	Base	10.7	17.9	100.0	0.0	95.3	2.9	94.9	6.5	0.677	0.074	15.1	2.1	0.743	0.097
1/S-4	Low	21.5	17.5	20.6	7.1	93.5	5.7	91.6	6.9	0.696	0.041	14.6	1.4	0.635	0.040
1/S-4	High	41.7	7.2	11.6	3.4	95.3	2.9	94.0	5.6	0.690	0.058	15.1	3.0	0.707	0.076
1/S2-0	Base	17.6	23.1	100.0	0.0	93.5	5.3	--	--	--	--	28.5	14.9	0.962	0.108
1/S2-0	Low	22.0	12.3	26.4	11.4	95.8	2.5	--	--	--	--	25.0	9.7	0.904	0.193
1/S2-0	High	41.0	24.7	18.9	9.1	94.0	5.4	--	--	--	--	27.5	7.8	0.949	0.218
1/S2-2	Base	28.8	12.7	100.0	0.0	94.5	5.3	94.2	7.3	0.683	0.039	24.4	5.7	0.908	0.107
1/S2-2	Low	30.2	12.6	30.5	16.7	96.3	2.1	90.6	11.8	0.686	0.063	27.3	6.9	0.916	0.096
1/S2-2	High	51.3	17.8	15.4	3.7	94.5	4.4	95.3	6.9	0.670	0.039	31.1	10.8	0.955	0.158
1/S2-4	Base	23.0	12.0	100.0	0.0	94.5	3.9	89.2	12.5	0.708	0.044	25.1	9.7	1.001	0.105
1/S2-4	Low	44.0	27.7	41.4	21.2	94.3	3.5	90.9	7.3	0.695	0.060	30.8	12.1	0.898	0.123
1/S2-4	High	58.2	21.2	14.0	6.0	96.[illegible]	2.3	85.5	20.0	0.696	0.048	32.6	11.8	0.955	0.112
No. of Subjects:		N=8		N=7		N=4		N=8		N=8		N=8		N=7	

TABLE 21. MEANS AND STANDARD DEVIATIONS OF SUBJECTS--EXPERIMENT II (continued)

Task	ACC	Mean Heart Rate	STD DEV Heart Rate	Mean Total Blinks	STD DEV Total Blinks	Mean Blink Duration	STD DEV Blink Duration	Mean P300 Latency	STD DEV P300 Latency	Mean P300 Amplitude	STD DEV P300 Amplitude	Mean EMG Standard	STD DEV EMG Standard
0-2	Base	73.8	8.9	22.7	10.3	150	13	441	30	15.5	13.3	13.7	4.8
0-2	Low	93.1	11.4	20.3	8.2	115	23	454	63	15.5	11.1	13.7	5.0
0-2	High	98.6	16.4	29.4	21.7	120	17	436	51	13.6	5.7	17.1	7.3
0-4	Base	77.6	12.6	24.4	9.5	138	15	430	70	16.0	11.6	14.5	2.7
0-4	Low	87.1	12.3	23.0	10.2	140	15	480	79	18.9	13.3	18.5	13.2
0-4	High	104.6	12.9	26.9	11.3	112	22	485	80	21.0	14.4	18.1	6.6
1/S-0	Base	76.0	13.8	6.4	5.6	145	19	424	108	5.4	7.9	17.2	11.4
1/S-0	Low	86.9	14.5	15.0	15.2	104	35	413	105	13.1	8.5	17.7	10.4
1/S-0	High	100.3	14.4	19.1	17.4	130	20	416	123	14.0	8.5	16.3	11.4
1/S-2	Base	76.8	14.1	9.3	8.9	145	21	426	47	13.7	6.2	21.4	16.7
1/S-2	Low	93.6	10.0	13.0	12.2	127	23	423	46	13.8	8.1	17.2	5.6
1/S-2	High	106.9	12.5	17.7	13.1	116	24	436	46	6.0	5.6	19.4	6.5
1/S-4	Base	80.6	10.1	9.9	10.5	116	30	462	88	18.7	4.6	18.1	6.9
1/S-4	Low	91.3	9.0	11.9	9.3	103	24	499	69	12.8	5.2	20.4	8.5
1/S-4	High	107.0	20.2	18.0	16.5	110	17	502	71	18.6	9.4	25.0	13.7
1/S2-0	Base	79.8	15.3	9.3	10.2	127	30	481	99	13.6	4.4	19.2	10.2
1/S2-0	Low	90.9	8.9	10.6	12.3	97	27	456	83	8.3	3.8	15.4	8.6
1/S2-0	High	106.8	14.1	16.6	16.0	103	19	448	65	14.4	14.9	16.3	5.5
1/S2-2	Base	79.6	18.5	8.6	6.8	138	26	467	66	12.1	4.5	27.5	15.1
1/S2-2	Low	88.1	16.0	12.9	11.4	125	18	474	50	18.5	14.5	24.7	9.5
1/S2-2	High	112.1	14.6	18.3	15.2	118	19	499	85	14.2	7.5	26.6	9.4
1/S2-4	Base	87.9	10.6	12.4	9.2	117	34	470	46	16.7	7.6	20.6	7.2
1/S2-4	Low	87.8	12.6	12.6	11.4	130	27	482	46	17.2	9.6	26.7	10.4
1/S2-4	High	105.3	14.7	20.7	18.0	115	22	486	66	20.5	23.5	31.2	14.3
No. of Subjects:		N=8		N=7		N=6		N=8		N=8		N=6	

TABLE 22. ANOVA RESULTS FOR SWAT RATING--EXPERIMENT I (NOISE PHASE)

Time				Mental				Psychological			
(P=.0001, LSD=.18)		(P=.0549, LSD=.17)		(P=.0001, LSD=.22)		(P=.0004, LSD=.06)		(P=.0001, LSD=.16)		(P=.0004, LSD=.23)	
Task	Mean	Noise	Mean	Task	Mean	Noise	Mean	Task	Mean	Noise	Mean
0-2	1.04	A	1.18	0-2	1.20	A	1.53	0-2	1.28	A	1.26
0-4	1.09	90	1.30	1/S-0	1.33	90	1.60	0-4	1.37	90	1.48
1/S-0	1.11	100	1.39	0-4	1.37	100	1.66	1/S-0	1.46	100	1.82
1/S2-0	1.19			1/S2-0	1.54			1/S2-0	1.50		
1/S-2	1.28			1/S-2	1.57			1/S-4	1.52		
1/S-4	1.37			1/S2-2	1.78			1/S-2	1.59		
1/S2-2	1.54			1/S-4	1.83			1/S2-2	1.67		
1/S2-4	1.70			1/S2-4	2.15			1/S2-4	1.76		
Plant	Mean (LSD=.13)	Targets	Mean (LSD=.13)	Plant	Mean (LSD=.16)	Targets	Mean (LSD=.16)	Plant	Mean (LSD=.11)	Targets	Mean (LSD=.11)
0	1.06	0	1.15	0	1.29	0	1.44	0	1.32	0	1.48
1/S	1.32	2	1.41	1/S	1.70	2	1.68	1/S	1.56	2	1.63
1/S2	1.62	4	1.54	1/S2	1.96	4	1.99	1/S2	1.71	4	1.64

TABLE 23. ANOVA RESULTS FOR SWAT RATING--EXPERIMENT II (ACCELERATION PHASE)

Time				Mental				Psychological			
(P=.0013, LSD=.29)		(P=.0017, LSD=.10)		(P=.0001, LSD=.28)		(P=.0069, LSD=.21)		(P=.0236, LSD=.29)		(P=.0001, LSD=.25)	
Task	Mean	ACC	Mean	Task	Mean	ACC	Mean	Task	Mean	ACC	Mean
0-2	1.00	Base	1.13	0-2	1.13	Base	1.47	0-4	1.33	Base	1.13
0-4	1.00	Low	1.22	0-4	1.21	Low	1.56	0-2	1.38	Low	1.34
1/S-0	1.13	High	1.34	1/S-0	1.38	High	1.83	1/S-0	1.38	High	2.09
1/S-4	1.21			1/S-2	1.67			1/S2-0	1.50		
1/S-2	1.25			1/S-4	1.67			1/S-4	1.54		
1/S2-0	1.25			1/S2-0	1.79			1/S-4	1.54		
1/S2-2	1.38			1/S2-2	1.96			1/S2-4	1.71		
1/S2-4	1.63			1/S2-4	2.17			1/S2-2	1.79		
Plant	Mean (LSD=.20)	Targets	Mean (LSD=.20)	Plant	Mean (LSD=.20)	Targets	Mean (LSD=.20)	Plant	Mean (LSD=.20)	Targets	Mean (LSD=.20)
0	1.00	0	1.19	0	1.17	0	1.58	0	1.35	0	1.44
1/S	1.23	2	1.31	1/S	1.67	2	1.81	1/S	1.54	4	1.63
1/S2	1.50	4	1.42	1/S2	2.06	4	1.92	1/S2	1.75	2	1.67

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